Impacts of major pests on forest growth and yield in the prairie provinces and the Northwest Territories: a literature review

B.H. Moody and P.A. Amirault

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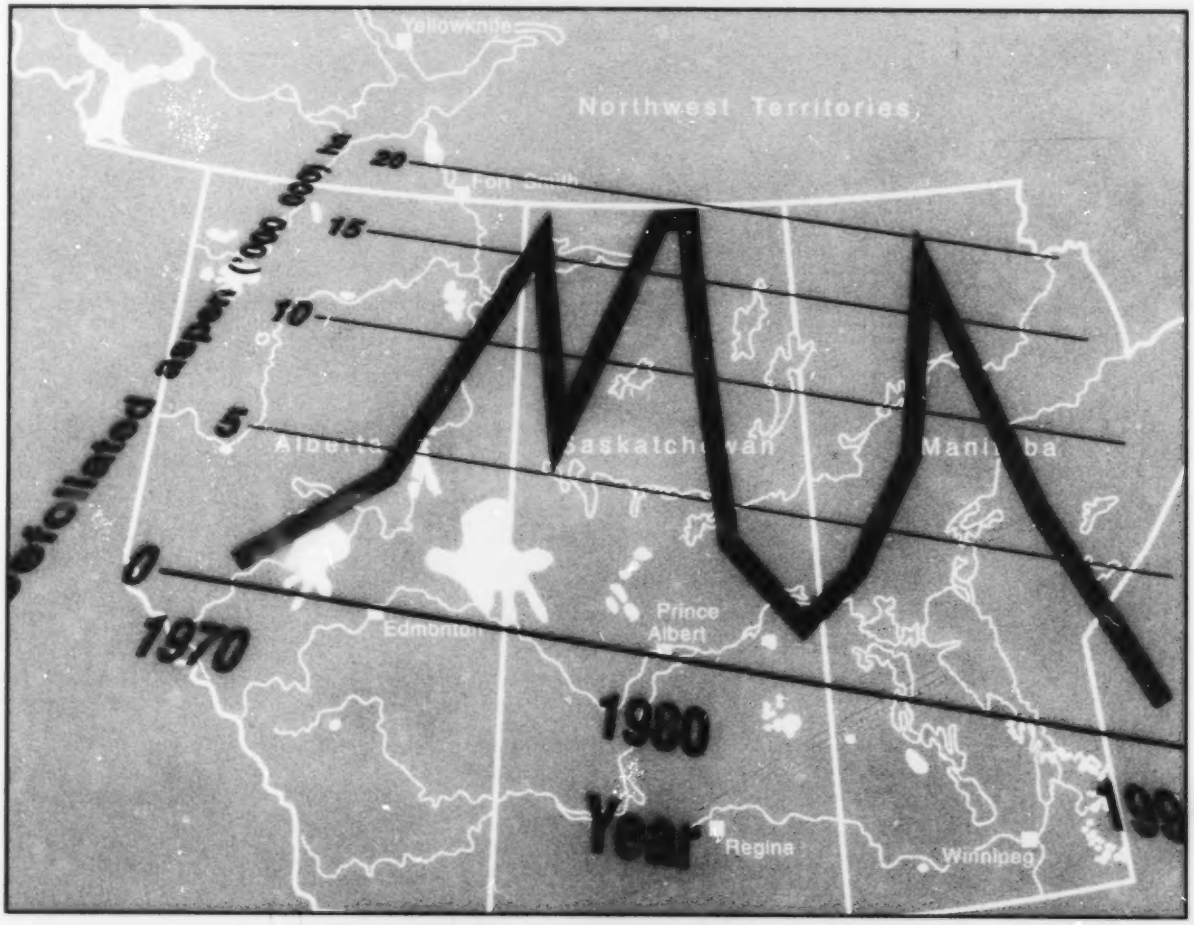

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IMPACTS OF MAJOR PESTS ON FOREST GROWTH AND YIELD IN THE PRAIRIE PROVINCES AND THE NORTHWEST TERRITORIES: A LITERATURE REVIEW

B.H. Moody and P.A. Amirault

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ABSTRACT

Literature pertaining to the impact of forest pests on timber productivity in the prairie provinces and Northwest Territories is reviewed. The discussion of impact is largely confined to growth loss and tree mortality, and quality reduction is considered in some cases. Potential and actual depletions caused by wood decay, armillaria root rot (*Armillaria* spp.), lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.), hypoxylon canker of aspen (*Hypoxylon mammatum* [Wahl.] J.H. Miller), atropellis canker of pine (*Atropellis piniphila* [Weir] Lohman & Cash), spruce budworm (*Choristoneura fumiferana* [Clem.]), jack pine budworm (*Choristoneura pinus* Freeman), mountain pine beetle (*Dendroctonus ponderosae* [Hopk.]), forest tent caterpillar (*Malacosoma disstria* Hbn.), and the spruce beetle (*Dendroctonus rufipennis* [Kirby]) are outlined. The significance of various depletions are discussed.

RÉSUMÉ

Ce document passe en revue l'ensemble des études réalisées concernant l'impact des ravageurs forestiers sur la productivité forestière dans les provinces des prairies et les Territoires du Nord-Ouest. L'analyse de l'impact se limite principalement au déficit de croissance et à la mortalité des arbres; la réduction de la qualité est examinée dans certains cas. Il est également question du décroissement potentiel et réel causé par la pourriture du bois, le charançon de l'écorce (*Armillaria* spp.), le faux gui du pin tordu (*Arceuthobium americanum* Nutt. ex Engelm.), le chancre hypoxylonien (*Hypoxylon mammatum* [Wahl.] H.J. Miller), le chancre atropellien (*Atropellis piniphila* [Weir] Lohman et Cash), la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* [Clem.]), la tordeuse du pin gris (*Choristoneura pinus pinus* Freeman), le dendroctone du pin ponderosa (*Dendroctonus ponderosae* [Hopk.]), la livrée des forêts (*Malacosoma disstria* [Hbn.]) et le dendroctone de l'épinette (*Dendroctonus rufipennis* [Kirby]). L'importance de divers types de décroissement est examinée.

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NOTE

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INTRODUCTION

Insect and disease caused problems continue to be a major concern of forest managers in Canada. Forestry Canada (1990) reported that the area treated for pest control in Canada did not drop below 1 000 000 ha annually between 1975 and 1985. This, however, excluded the largest operation in Alberta, Saskatchewan, Manitoba, and the Northwest Territories (the Northwest Region), that is a mountain pine beetle (*Dendroctonus ponderosa* Hopk.) control program conducted by the Alberta Forest Service from 1980 to 1986. About 15 000 ha of lodgepole pine (*Pinus contorta* Dougl.) forest were treated at a cost of over $6.2 million (Alberta Forest Service 1985, 1986). As the intensity of forest management increases throughout the Northwest Region, pest concerns will also be magnified. This paper summarizes and interprets existing information about the impact of insect and disease pests on the forests of the Northwest Region.

Forest insects and tree diseases may affect the timber inventory by causing tree mortality and growth reductions. It can also reduce timber quality. This may seriously disrupt harvest schedules of affected stands and reduce yields in subsequent generations (MacLean 1990). Other losses caused by pests include delayed regeneration, stocking deficiencies, changes in stand composition, site degeneration, and constrained management options by loss of pest-susceptible species (Whitney et al. 1983).

Pest-caused tree mortality may be severe and extensive during the period of a few years, as with an extensive bark beetle outbreak, or it may be a gradual stand depletion extending over a long time, such as the damage caused by dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) infestations. Decreased height and/or diameter growth results in decreased volume yields in live stands. These reductions can be intermittent, periodic, or sustained. All forms of growth reductions usually result from some interference with vital tree functions, namely root absorption, transpiration, and photosynthesis. Intermittent growth reductions (sporadic and of short duration) are of little consequence except that they sometimes condition trees for attack by other destructive agents. Periodic growth reductions are more serious because wood increment becomes substantially less than normal and trees sometimes remain vulnerable to death for years. Sustained growth reductions, such as those resulting from continued attacks by defoliators, dwarf mistletoe, and perennial cankers, may double the time required for trees to reach merchantable size. Mortality in such trees is higher than normal. Insects and diseases can lower the quality of wood through such processes as boring and decay. Ultimately these losses affect the sustainable annual allowable cut.

This literature review summarizes quantitative studies of tree mortality, growth reduction, and to a lesser degree, quality reduction related to insect and disease damage in the region. MacLean (1990) noted that the determination of the impact of damaging agents on stand growth and yield requires a measurement of the severity and duration of the stress (e.g., defoliation), a determination of the growth rates and mortality of sample trees during the period of stress, and an estimate of the potential growth and mortality if the stress had not occurred. A common format is followed throughout this report. Comments of an introductory nature are made for each pest, followed by discussions on growth reduction, tree mortality, and quality reductions when applicable. Sources include both published and file reports of the Forest Insect and Disease Survey (FIDS), as well as other published sources. Studies from neighboring jurisdictions are reviewed where regional information is lacking, or to complement regional data. The tree species under consideration are white and black spruce (*Picea glauca* [Moench] Voss) and (*Picea mariana* [Mill.] B.S.P.), red, jack, and lodgepole pine (*Pinus resinosa* Ait., *Pinus banksiana* Lamb., and *Pinus contorta* var. *latifolia* Dougl.), balsam fir (*Abies balsamea* [L.] Mill.), trembling aspen (*Populus tremuloides* Michx.), and balsam poplar (*Populus balsamifera* L.). Nomenclature for tree diseases follows Hiratsuka (1987), and for forest insects it follows Ives and Wong (1988). These two publications are recommended as sources of illustrations of the various pests.

WOOD DECAY

Sterner and Davidson (1982) reported that the amount of wood destruction due to decay in Canada's commercial forests between 1977 and 1981 was 25 million m^3 annually. In the broadest

sense, wood decay can be said to be any wood deterioration caused by insects, marine animals, fungi, bacteria, and physical factors of the environment (Manion 1981). In this review discussion is limited to some of the major decays caused by various fungi. For practical purposes decay or rots are classified on the basis of their location within the tree (e.g., root or trunk rots) or according to the type of wood affected (i.e., heart and sap rots).

Trunk rots are common in the forests of the Northwest Region. Except for the fruiting body (conk or mushroom), trunk rots are hard to detect until the tree is harvested. The incidence of trunk rot is extremely variable among and within host species and is related to factors such as tree age, growth rate, stand history, and site (Whitney et al. 1983). These decays cause losses in wood fiber and structural strength, and may affect physical appearance by the association of stain. Root rots are also very common and their decay causing fungi often extend into the lower bole of the tree resulting in butt rots. Symptoms of root rot are a loss in tree vigor, yellowing of foliage, decrease in growth and eventually death. In general, *Populus* species and balsam fir are considered to be highly prone to wood decay, whereas spruce, pine, and larch (*Larix* spp.) are only moderately affected.

Decay is commonly expressed as a percentage of gross or merchantable volume; it is generally calculated from analyses of tree dissections. The expression of decay as a percentage of volume, however, does not lend itself well to direct estimates of either mortality or growth loss impacts. To overcome this, Gross (1985) and Manion (1981) recommend that decay figures should be applied to growth rates by proportionally reducing them relative to the decay rates for various age classes.

Decay of Trembling Aspen and Balsam Poplar

A significant amount of advanced decay is common in trembling aspen and balsam poplar in the Northwest Region. This is often a limiting factor in the utilization of these species, not only industrially but as windbreak or amenity trees (Thomas 1968; Hiratsuka 1987). *Phellinus tremulae* (Bondartsev) Bondartsev & Borisov (= *Fomes igniarius* (L.:Fr) Kickx) is the most common and important trunk rot-causing organism (Kirby et al. 1957; Thomas et al. 1960; Hiratsuka and Loman 1984; Hiratsuka et al. 1990). Also called the "false tinder conk", this fungus is essentially a wound invading parasite that causes a white trunk rot with conspicuous black zone lines surrounding each decay column (Hiratsuka and Loman 1984). This type of decay frequently extends into (or occurs in) the basal portion of trees, but seldom, if ever, into the roots (Ross 1976). *Peniophora polygonia* (Persoon: Fries) Boudier & Galzin (= *Corticium polygonium* (Persoon: Fries) is the second most important trunk rot in the region (Hiratsuka 1987), while *Armillaria ostoyea* (Romagnesi) Herink is the most common cause of butt and root rot of trembling aspen in Alberta (Hiratsuka et al. 1990). There are more species of decay fungi associated with root and butt rots than with trunk rots. The amount of decay produced in terms of wood volume is usually less for the former types (Kirby et al. 1957; Thomas et al. 1960), but root rot can predispose trees to premature mortality and windthrow (Hinds 1985). Other fungi that cause decay in aspen and poplar are discussed in Hiratsuka (1987) and Hiratsuka et al. (1990).

The measurement and classification of decay and stain in aspen and poplar has been problematic. Basham (1987) noted that various studies involving the measurement of decay are not always comparable due to variability in the way stain was dealt with (i.e., measured or not measured). Hiratsuka et al. (1990) subsequently produced a guide to measure and classify aspen decays and stains (in Alberta). They proposed five categories of major wood defects for decay and stain measurement. These are illustrated in their publication along with external indicators, and methods of sampling and measuring defects are outlined.

The consequences of decay and stain are dependent on the end use of the wood (Hiratsuka et al. 1990). The bleached chemical (kraft) pulping process is relatively tolerant of decay and not affected by stain, while chemithermomechanical pulping requires wood with low levels of decay and stain. These defects lead to a loss of yield and increased bleaching costs. Stain levels up to 20% are tolerated in the production of oriented strandboard because most decay is lost during processing. Stain is not acceptable in solid wood products (e.g., furniture), and the levels of stain and decay commonly found in the Northwest Region limit the utilization of aspen for lumber (Kirby et al. 1957).

There have been a number of studies to quantify stain and/or decay in aspen and poplar in the Northwest Region (Black and Kristapovich 1954;

Paul and Etheridge 1958; Thomas et al. 1960; Bailey and Dobie 1977; Pedology Consultants 1982; Maier and Darrah 1989). In most cases, the authors listed decay rates relative to stand age (Tables 1 and 2). A comparison of these rates is not straight forward due to differences in methodology applied in the various studies. While the amount of decay is known to increase with stand age, other factors such as stem damage from frost scars, and fire scars (Kirby et al. 1957; Hiratsuka 1987), clonal influences (Wall 1971), and whether the stand originated from cutting (more decay) or after fire (Basham 1987) have been cited.

Thomas et al. (1960) conducted surveys of trembling aspen and balsam poplar stands in 8 localities in west-central Alberta. Their objective was to obtain cull factors that had general application to provincial and industrial requirements. Sites were categorized as dry, mesic, or wet. The presence of rot was ascertained by stem dissection, and pathogens were identified from fruiting bodies and cultures. A total of 835 aspen (>9 cm diameter at breast height (dbh) and 23–117 years old) were examined from 28 sample plots, and 527 balsam poplar (>9 cm dbh and 24–158 years old) from 32 sample plots were dissected (Thomas et al. 1960). The aspen had a higher incidence of wood rotting fungi than the balsam poplar, and slightly more decay was present on wet sites because of an increased amount of false tinder conk activity. The differences between species became less pronounced as stands aged: on mesic sites, 78% of the aspen and 30% of the balsam poplar in 50-year-old stands were infected to some degree; in 80-year-old stands the rates were 85 and 75%, respectively. Overall, 73% of the aspen and 61% of the balsam poplar from all age classes were decayed. In addition, trees of both species were infected by stain-producing fungi. The average loss of gross volume due to decay for all trees examined was 25% and 10% for trembling aspen and balsam poplar, respectively. Butt infections accounted for 31.5% of the infections (10.8% of the rot volume), and trunk infections accounted for 68.5% (89.2% of the rot volume).

Two other studies conducted in Alberta (Pedology Consultants 1982; Bailey and Dobie 1977) used standards whereby logs that appeared to be more than 50% decayed, during a cursory examination, were rejected from further study. This could explain the comparatively low decay percentages reported in these studies. Also in Alberta, Paul and Etheridge (1958) analyzed aspen logs for decay at various logging sites. They did not reject logs with advanced decay, and not surprisingly, obtained decay volumes significantly higher than both Pedology Consultants (1982) and Bailey and Dobie (1977) (Table 1). Basham (1987) speculated that Paul and Etheridge (1958) may have included stain with decay, which would inflate their values. He came to this conclusion because the authors failed to mention how stain or discoloration was treated, and went on to point out that the volume of stain can be 3–5 times that of decay. It is not known why decay rates in the oldest stands sampled by Paul and Etheridge (1958) are less than that for some younger age classes.

Maier and Darrah (1989) conducted a cull survey in mature and overmature trembling aspen and balsam poplar stands in west-central Alberta. They identified and measured decay in 985 aspen and poplar trees using the three category system (advanced decay, incipient decay, and stain) described by Hiratsuka and Loman (1984). No statistically significant differences in percent decay were obtained among dbh classes, height classes, site indexes, stump ages, stand ages from photo-interpretation, external decay indicators, or cull suspect classes. Absolute decay volumes, as opposed to culls deducted from merchantable volumes, were significantly related to dbh, tree height, and stump age. Maier and Darrah (1989) concluded that stump age could be useful in estimating some levels of decay, although they had difficulty determining average stand ages because of the variability within sampled stands. They indicated that tree size was a better estimator of decay than age, and they developed regression equations that predict defect volumes based on dbh and height. Maier and Darrah (1989) reported that on an individual sample tree basis advanced decay averaged 7%, advanced plus incipient decay averaged 10%, and total decay (including stain) averaged 39% of the gross volume. All stands sampled were judged to be usable for chip production, while pulp production was limited by stain.

Kirby et al. (1957) studied the growth and yield of trembling aspen in Saskatchewan and concluded that decay was the most serious factor limiting the utilization of the species based upon dissection of 434 trees of various sizes from 145 plots throughout the province. The authors separated stain and decay on the basis of wood soundness. They reported that 297 (68.4%) of the trees were decayed to some extent, and that virtually all trees over 120 years were decayed. Table 1 outlines the age–decay

Table 1. Age–decay relationships in trembling aspen stands in the Northwest Region (after Hiratsuka and Loman 1984)

Age class (yrs)	Decay (% gross volume)				
	Manitoba Eastern Sask.[a]	Central Alberta[b]	Central Alberta[c]	Southwest Alberta[d]	Saskatchewan[e]
31-40	–[f]	12.0	–	–	4.0
41-50	1.8	14.0	–	–	7.0
51-60	3.2	30.0	6.2	–	10.0
61-70	7.1	40.0	–	–	13.0
71-80	14.4	42.0	8.4	8.7	16.0
81-90	21.3	40.0	–	–	18.0
91-100	25.2	36.0	12.2	–	22.0
101-110	31.1	33.0	–	–	25.0
111-120	36.9	30.0	–	–	28.0
121-130	41.9	–	–	–	31.0

[a] Black and Kristapovich (1954).
[b] Paul and Etheridge (1958).
[c] Bailey and Dobie (1977).
[d] Pedology Consultants (1982).
[e] Kirby et al. (1957).
[f] Age classes not considered in study.

Table 2. Age–decay relationships in balsam poplar stands in Alberta (Hiratsuka and Loman 1984)

Age class (yrs)	Decay (% gross volume)		
	Lesser Slave Lake		Rocky–Clearwater Forest[c]
	1958[a]	1977[b]	
31–40	2.9	–[d]	–
41–50	8.7	6.2	–
51–60	8.2	–	–
61–70	7.4	–	–
71–80	8.4	5.0	7.4
81–90	10.1	–	–
91–100	11.4	5.5	–
101–110	13.3	–	–
111–120	15.2	–	–
121–130	17.3	–	–
131–140	19.4	–	–
141–150	21.3	–	–
151–160	22.9	–	–
161–170	24.5	–	–
171–180	–	–	–

[a] Paul and Etheridge (1958).
[b] Bailey and Dobie (1977), preselected logs.
[c] Pedology Consultants (1982).
[d] Age classes not considered in study.

relationship developed from study trees. Kirby et al. (1957) concluded that trembling aspen stands of 70–80 years of age were not overmature but were susceptible to decay to a degree that warranted harvesting (from the point of view of maximizing timber yields).

Black and Kristapovich (1954) determined the amount of cull caused by decay after analyzing 847 aspen trees from 15 sample plots in aspen stands in Manitoba and eastern Saskatchewan (Table 1). The volumes were calculated according to Manitoba regulations for measuring aspen pulpwood. Their results compare fairly favorably with those obtained by Kirby et al. (1957) for stands aged 70–130 years.

A lot of information exists on the decay of aspen in the Northwest Region; however, the subject is difficult to interpret due to the variety of results produced by, and methodologies used during various investigations. The statement by Kirby et al. (1957), "It is important to have some idea of the cull content of aspen, no matter how broad and dependent upon averages that knowledge may be. It is also essential to know what effect the cull content has on present utilization and how the unfortunate limitations of the species might be overcome", is endorsed in this report.

Decay of Conifers

Hiratsuka (1987) summarized the decay of conifers in the prairie provinces and referred to *Phellinus pini* (Thore:Fr.) Pil. (= *Fomes pini* (Thore:Fr.) Lloyd.) as being the most important decay fungus, economically. He listed the 15 most common decay organisms and explained that in most cases infections are initiated through branch stubs and stem and branch wounds by airborne basidiospores. *Armillaria* spp. and *Inonotus tomentosus* (Fr.) Gilbertson (= *Polyporus tomentosus* Fr.) can also spread through forest soils and root contact. Trees with advanced decay are often culled, especially in mature and overmature stands as decay increases with stand age. Other problems brought on by the decay of conifers include increased susceptibility to windthrow as a result of root or butt decay, and stand openings (Hiratsuka 1987).

Lodgepole, Jack, and Red Pines

Loman and Paul (1963) surveyed lodgepole pine in sections B19a (Lower Foothills) and B19c (Upper Foothills) (Rowe 1972) of the boreal forest in Alberta, to determine decay relationships for the species. In total 2436 trees were dissected from 61 sample plots in 6 distinct areas. *Phellinus pini* and *Inonotus tomentosus* were the most commonly found fungi isolated from white pitted trunk rots, *I. tomentosus* and *Pholiota alnicola* (Fr.) Sing. (= *Flammula alnicola* (Fr.) Quél.) were the prevalent fungi isolated from white pitted root and butt rots. *Coniophora puteana* (Schum.:Fr.) Karst. were the dominant fungi isolated from brown cubical root and butt rots, whereas *Peniophora pseudo-pini* Weres. & S. Gibson were the main fungi isolated from red heartwood stain (Loman and Paul 1963).

Tree volumes and the volume of heartwood stain and decay were calculated. Results showed that the volumes of stain and decay were quite low, and that most of the advanced decay was restricted to a small number of trees (Loman and Paul 1963). The authors suggested that losses owing to decay are negligible in stands up to 100 years, 5% in stands 100–170 years, and 8% in stands older than 170 years. Volumes of stain were larger than those for decay in all age classes, averaging 4.3% of tree volume for all trees, compared to 2.0% for decay.

There is little information on the decay of jack pine in the Northwest Region. Studies conducted in Ontario (Morawski et al. 1958; Basham 1967) indicated that the rate of decay increased with age and was more pronounced on dry sites. The primary wood decay agent for jack pine in Ontario was *Phellinus pini*. Suitable entry points for decay fungi include branch stubs, dead roots, dead tops, and other trunk injuries (Basham 1966). Basham (1967) dissected 1612 jack pine from Ontario (west of Thunder Bay) and calculated gross merchantable volumes, as well as tree (tops and stumps excluded) and defect volumes. Defects included both advanced and incipient decay. He found that the percentages of total merchantable volume decayed was 0.2, 1.4, 2.7, 6.9, 12.2, and 38.8% for trees between the ages of 41–60, 61–80, 81–100, 101–120, 121–160, and 161–200, respectively.

Information on the decay of red pine is scant. Gross (1985) did not report any depletion estimates because of decay for the red pine growing stock in northwestern Ontario. This suggests that defect surveys (Morawski et al. 1958; Basham and Morawski 1964), on which depletion estimates were based, found only trace levels.

White and Black Spruce

The most extensive survey of white spruce decay in the boreal forest of the Northwest Region is that reported by Denyer and Riley (1954). They dissected 1347 trees from the three prairie provinces and calculated tree and decay volumes. The primary causal agents of stem rots, which accounted for the greatest volume losses, were *Phellinus pini* and *Haematostereum sanquinolentum* (Alb. & Schw.:Fr.) Pouzar, and a third species that was not identified. Four species of root rot fungi (*Coniophora puteana, Inonotus tomentosus, Pholiota alnicola,* and *Armillaria ostoyae*) were considered to be important (Denyer and Riley 1954). A total of 513 decay infections were encountered during dissections. Root rot fungi were responsible for 450 and stem rot fungi for 163 infections (trees were dissected above a stump height of 15–60 cm). Root rots were responsible for 35.2% of the total decay volume, and stem rots 64.8%, with *P. pini* being the leading cause of volume loss. As with other species the amount of decay reported for white spruce increased with age. On trees less than 60 years old there was no decay; the average decay rates for trees over 70 years of age are given in Table 3.

Etheridge (1958) conducted decay surveys on twelve sample plots in the Rocky–Clearwater and Bow–Crow forests of southwestern Alberta. He dissected 456 trees of subalpine spruce (white, Engelmann [*Picea engelmannii* Parry], and black spruces) and calculated gross and decay volumes. His decay volume estimates were comparable but consistently lower than those obtained by Denyer and Riley (1954). Both the rate of decay and the growth rate of subalpine spruce on moist (as opposed to dry) sites were said to be greater than that reported by Etheridge (1958).

Table 3. Average decay percentages for white spruce of various ages from the boreal forest of the prairie provinces

	Decay (% avg tree volume)		
Age	Denyer and Riley 1954	Etheridge 1958	Riley 1955
70	0.9	0.0	–[a]
80	1.0	0.0	0.0
90	1.4	0.0	–
100	2.0	0.0	2.6
110	2.5	0.0	–
120	3.0	1.5	2.9
130	3.5	2.4	–
140	4.1	3.3	4.0
150	4.6	3.3	–
160	5.1	3.6	4.9
170	5.7	4.4	–
180	6.3	4.5	6.7
190	7.1	5.1	–

[a] No value reported for this age class.

Riley (1955) combined information collected in Saskatchewan by Denyer and Riley (1954) with some of his own research to produce the values presented in the final column of Table 3. These represent averages for 781 trees from 28 sample plots. The author did not consider the amount of decay to be excessive, and noted it was concentrated in a small number of trees, which were classed as "total cull". The most important losses in white spruce arose from wind breakage of trees weakened by root and butt rots, which tended to reduce stand density (Riley 1955).

Whitney (1961) examined the roots of 656 white spruce (7–180 years of age) from two locations in Saskatchewan and one in Manitoba. His goal was to investigate the role of wounds as infection courts for root-rotting fungi. Root rot or stain was found on 82.7% of the trees with infection being traced to wounds in 53.5% of diseased roots (an additional 37.9% of the diseased roots had infections too advanced for the point of infection to be determined). Twenty-seven percent had root-rotting or staining fungi that where determined to have entered through wounds caused by root weevils (*Hylobius* spp.). This was the most common avenue of infection and was particularly severe on sites with deep duff layers and near rotten logs or stumps. The Warren rootcollar weevil (*Hylobius warreni* [Wood]) was the main weevil species involved, and the most common fungi were *Inonotus tomentosus* and *Armillaria ostoyae*. Decay was consistently most advanced in heavily wounded portions of root systems. Other types of wounds associated with root-rot and stain were: rootlets killed by excessive moisture; compression wounds caused by rubbing against stones or other roots; wounds caused by animal trampling; root canker wounds (cause unknown); and dead root ends (cause unknown) (Whitney 1961).

Denyer and Riley (1954) did not obtain a good relationship between tree age and percentage decay for the 110 black spruce they dissected from

stands in Saskatchewan and Manitoba. Average percentage decay was, however, related to dbh and ranged from 2.5 to 6.1% for trees of 7.6 cm and 38.1 cm at dbh, respectively. The percentage of decay in black spruce was roughly twice that of white spruce of equal diameter. The important fungi involved were the same as those in white spruce (Denyer and Riley 1954).

Balsam Fir

Balsam fir is currently a less important commercial species of prairie province forests. There are indications that it may become more prevalent in localized areas as it tends to dominate openings in spruce stands in parts of the region (Riley 1955). Balsam fir is characteristically fast growing, short lived, and very susceptible to "red heart rot" caused by the fungus *Haematostereum sanguinolentum* (Whitney 1952).

Denyer and Riley (1954) dissected 166 balsam fir from stands throughout the prairie provinces from which they developed relationships between tree age and percent decay. Decay was minimal in trees up to 40 years, reached 6.7% at age 50, and peaked at 12% at 100 years. Above 100 years of age the percentage of decay remained fairly constant. The authors speculated that sample trees over 100 years were residuals that were comparatively free from decay.

A study conducted in Quebec identified injuries caused by larvae of the Couper collar weevil (*Hylobius pinicola* [Couper]) as the primary entry court for root and butt rot fungi on dominant and codominant balsam fir (Smerlis 1961). The principle fungus involved was *Scytinostroma galactinum* (Fr.) Donk. Both the weevil and the fungus are native to the Northwest Region.

ARMILLARIA ROOT ROT

Armillaria root rot is one of the most important diseases in young coniferous stands in the prairie provinces (Hiratsuka 1987). It has been recognized as one of the main mortality agents of young lodgepole pine in Alberta (Baranyay and Stevenson 1964; Amirault and Pope 1989), jack pine and white spruce in Saskatchewan (Emond and Cerezke 1989), and red pine in Manitoba (Moody and Cerezke 1986). Less is known about the fungus as a cause of growth loss and mortality in older coniferous and deciduous forests in the Northwest Region (Mallett 1990). Armillaria root rot in the region had been attributed to *Armillaria mellea* (Vahl:Fr.) Kummer until Mallett (1990) showed that at least three species were involved. He identified *Armillaria ostoyae* (Romag.) Herink as the most common species occurring on a wide variety of coniferous and deciduous hosts. The other species were *Armillaria sinapina* Bérubé & Dessureault (primarily on deciduous hosts) and *Armillaria calvescens* Bérubé & Dessureault on both coniferous and deciduous hosts.

Armillaria spreads primarily as a vegetative mycelium, either by root-to-root contact or by rhizomorphs. Small trees infected by this pathogen are usually killed quickly while larger trees can continue growing for some time after infection (Hiratsuka 1987). Depending on the tree age and percentage of the root system killed, reduction in radial growth is evident from 2 to 10 years prior to tree death. *Armillaria* usually remains in tissues beneath the ground, but other important root-decay fungus such as *Inonotus tomentosus* can extend into the lower bole. Losses caused by *Armillaria* have often been included with depletion caused by decay in regional studies.

Whitney (1973) quantified root rot losses in 23 white and black upland spruce stands in the Candle Lake area of Saskatchewan, including areas of standing dead or windfallen trees (disease centers). He examined all spruce with a dbh greater than 9.1 cm on one 0.2 ha plot in each stand. The trees were classified as either healthy, diseased, dead, or windfallen and examined for the presence of root rot. Age, height, and volume were determined for sample trees. In 14 black spruce stands (73–111 years old measured at breast height), an average of 30% of the trees had died from root rot, and 14% were diseased (infected with root rot but still alive). In 5 stands containing a mixture of black and white spruce (71–85 years), an average of 35% were dead and 20% diseased. The remaining 4 stands were white spruce–aspen (70–88 years) and averaged 41% mortality and a 13% incidence of disease. Volume losses due to tree death averaged 27% in black spruce stands, 31% in black–white spruce stands,

and 31% in white spruce–aspen stands. The main decay fungi involved were *Inonotus tomentosus, Armillaria* sp., and *Coniophora puteana* (Whitney 1973).

A study by Whitney (1978) in northwestern Ontario on 1479 trees revealed that Armillaria root rot was present in the roots of 42, 36, and 31% of balsam fir, white spruce, and black spruce trees, respectively. Study stands were selected to include a range of sites, age classes, species compositions, and root rot intensities. Not only did *Armillaria* kill trees outright, but its presence led to weakened roots and increased susceptibility to windthrow.

LODGEPOLE PINE DWARF MISTLETOE

The dwarf mistletoes are perennial parasitic flowering plants that depend on living hosts (trees) for support, water, and most nutrients (Baranyay 1970). Lodgepole pine dwarf mistletoe (*Arceuthobium americanum*) is the most important dwarf mistletoe in the region. Its greatest impact is on jack pine and lodgepole pine in Alberta and on jack pine in Saskatchewan and Manitoba. In fact, Hiratsuka (1987), based on information then available, noted that this disease caused the largest amount of annual loss in merchantable lodgepole and jack pines in the prairie provinces. Lodgepole pine dwarf mistletoe colonizes trees of all ages, causing reduced vigor, diameter and height growth, increased mortality, and reductions in wood quality (Hawksworth and Johnson 1989). A second species, eastern dwarf mistletoe (*A. pusillum* Pk.), occurs on black spruce in Manitoba and eastern Saskatchewan (Hiratsuka 1987). This species causes relatively little damage compared to lodgepole pine dwarf mistletoe and is not discussed here.

The most conspicuous symptom of dwarf mistletoe infection is the presence of abnormal tufted growths of small branches on trees or shrubs called witches' broom. The size and shape of brooms vary depending upon the tree species; those on jack pine tend to be largest, while those on white spruce are small but very dense, and those on lodgepole pine are intermediate in size (Baranyay 1970). Old witches' brooms sometimes weigh several hundred kilograms and are easily broken off; the resulting wounds provide openings for fungi to colonize. As the disease intensifies, nutrients are increasingly directed from healthy portions of the tree to brooms and branch and bole swellings, which lead to top kill, growth reduction, and mortality.

Arceuthobium americanum is widespread throughout the region. It occurs as far north as Lake Athabasca, Saskatchewan and Flin Flon, Manitoba. Incidence levels have been 73% of the stands at the south end of Lake Winnipeg, Manitoba, and 100% near Prince Albert, Saskatchewan (Elliott et al. 1967). Surveys of dwarf mistletoe on lodgepole pine in Alberta estimated that 10% of the lodgepole pine stands were infected (Baranyay and Safranyik 1970).

Research on mistletoe infected lodgepole pine in Alberta (Baranyay and Safranyik 1970) indicated stem volume losses of 18–32% in five stands ranging in age from 37 to 117 years. Height growth of trees was particularly reduced by mistletoe infection on dry sites. The volume of trees was seriously reduced when infection occurred before stands reached 25 years of age. Mortality attributable to dwarf mistletoe ranged from 0 in the 37-year-old stand to 26% in the 117-year-old stand. Overall annual loss caused by dwarf mistletoe in lodgepole and jack pine stands in Alberta has been estimated at 270 000 m^3 (Baranyay 1970). Other effects include decreases in the value of wood because of larger knots, increased stem taper, and bole swellings. It is assumed that dwarf mistletoe affects jack pine in a similar manner and that these loss figures can be used to gauge the seriousness of the disease throughout the region.

Hawksworth and Johnson (1989) cited various impacts of dwarf mistletoe on lodgepole pine in areas adjacent to the Rocky Mountains. Hawksworth (1958) established a direct relationship between low vigor of trees (as judged by crown appearance) and intensity of dwarf mistletoe infections. Trees of high vigor were found to have greater volumes than those of low vigor. Low intensities of dwarf mistletoe infections have no measurable effect on diameter growth (Hawksworth and Johnson 1989). The threshold for measurable growth loss appears to be when infections occur throughout half or more of the crown. Dwarf mistletoe impacts height growth to a greater degree than diameter growth (infected trees are

prone to dead tops) (Hawksworth and Johnson 1989). Tree mortality tends to be greatest in stands with heavy infection, and is most pronounced in stands infected at an early age. Finally, wood defects in lodgepole pine associated with mistletoe infections include: swollen and distorted stems; large knots that reduce lumber grades; and infected wood weakened due to a high proportion of ray tissues and shortened, distorted tracheids (Hawksworth and Johnson 1989).

ATROPELLIS CANKER OF PINE

Atropellis canker of pine is caused by *Atropellis piniphila* (Weir) Lohman & Cash. Airborne ascospores infect the host near branch whorls causing perennial stem and branch cankers, copious resin flow, and a blue-black wood stain (Hopkins 1985). Cankers grow more rapidly longitudinally than around the stem resulting in an elongated shape. Atropellis canker is common throughout much of the range of lodgepole pine in Alberta, and on this and other hosts throughout western North America (Hiratsuka 1987). The fact that it does not infect jack pine limits its distribution in the Northwest Region, but it is considered to be an important disease of lodgepole pine and has a high incidence in several areas in Alberta (Hiratsuka 1987).

Baranyay et al. (1973) did stem analyses on lodgepole pine infected to various degrees (based on the percentage of bark circumference infected) from three sites in Alberta. They concluded the disease can negatively affect both height and diameter growth in cases of severe infection. Volume reductions up to 56.5% were reported, and mortality was said to increase for severely infected trees. Nevill et al. (1989) found that heavy infection (based on the number and size of cankers) reduced diameter growth and tree volumes, but not height growth in stands in the interior of British Columbia. They also measured the amount and grade of lumber that was recoverable from infected trees. The volume of lumber recovered from infected trees was 28.7% less than from uninfected trees; lumber grades were negatively affected, and the monetary values of the stands were reduced (Nevill et al. 1989). Resin flow from cankers complicates debarking, and stain associated with cankers increases bleaching costs during pulping (Baranyay et al. 1973).

Hopkins (1963) noted that atropellis cankers on lodgepole pine almost always develop on northern aspects of trees. The incidence of infection is apparently positively related to stand density as is tree mortality (Hopkins 1985). Culture treatments are available to help reduce the risk of infection and growth losses (Hopkins 1985; Stanek et al. 1986).

HYPOXYLON CANKER OF ASPEN

Hypoxylon canker of aspen, caused by *Hypoxylon mammatum* (Wahl.) J.H. Miller, is common throughout much of the range of trembling aspen (Hiratsuka 1987). The fungus is a wound parasite that causes cankers, which gradually enlarge until the stem is girdled. Trees infected on the lower stem normally die within five years and become prone to breakage (Hiratsuka 1987). Trembling aspen is very susceptible to *H. mammatum*, largetooth aspen (*Populus grandidentata* Michx.) is occasionally infected, and balsam poplar is rarely infected (Hinds and Harrell 1986). While considered to be one of the most important aspen diseases in the prairie provinces, the fact that it is most common on injured or stressed trees indicates the secondary nature of the disease (Hiratsuka 1987).

In Alberta, hypoxylon canker is found throughout the range of trembling aspen with the exception of the Subalpine Forest Region of the Rocky Mountains (Baranyay 1963). In a study by Baranyay (1967), 45.1% of the aspen (average age 24 years) on a 0.135 ha plot in Elk Island National Park were either killed or infected. This number increased to 49% during the following three years. All stem cankers were located below 3 m and 75% faced north or northeast. The disease was not confined to a particular crown class and infected trees were

killed in 4–8 years. While Baranyay (1967) stated that the disease did not cause increment loss during the infection period, the high infection rate and mortality showed that *Hypoxylon* is a serious disease of aspen stands in Alberta.

In Saskatchewan and Manitoba, the incidence of hypoxylon canker infected trees ranged from 4.5% to 58% with a mean of 18% in 13 sample plots established across the provinces. The higher percentages of infected trees occurred on or along the southern border of the aspen zone in both provinces (Elliott et al. 1967).

Manion and Griffin (1986) reviewed studies that addressed the role of environmental factors in the incidence and impact of hypoxylon canker of aspen. They concluded many studies were inadequate because of limited sampling and minimal statistical testing. An exception was the study conducted by Anderson and Martin (1981), where the factors involved in the establishment of hypoxylon cankers on the stems of trembling aspen were identified. Their work involved eight years of observations on 74 plots in northern Minnesota. Factors found to be positively correlated with *Hypoxylon* incidence were: length and intensity of forest tent caterpillar defoliation immediately before the study period; presence of the poplar borer *Saperda calcarata* Say; and initial density of hypoxylon canker in the upper boles of plot trees. Infection intensities were negatively correlated with stand density while the relationship between site index and canker incidence was unclear. Infection rates did not vary with tree size or age. Manion and Griffin (1986) pointed out that the latter observation is not consistent with results of other studies, and suggested the relationship may be inconsistent or affected by genetic resistance to canker infection in older stands. Copony and Barnes (1974) noted that in studies relating the incidence of hypoxylon canker to site and biotic factors, the clonal structure of aspen stands should be recognized, and the clone should be used as the basic unit of sampling.

Aspen comprises a major portion of the timber volume in the Northwest Region, yet only a small portion of it has been harvested each year in the past. Thomas et al. (1960) stated that losses caused by *Hypoxylon* are comparable to, if not greater than, those caused by decay fungi in the region. With the current increases in utilization and management of aspen, the impact of hypoxylon canker may become more apparent.

SPRUCE BUDWORM

The spruce budworm (*Choristoneura fumiferana* [Clemens]) is one of the most destructive forest pests in Canada. Sterner and Davidson (1982) reported that the estimated annual depletion between 1977 and 1981 resulting from spruce budworm defoliation for mortality and growth reduction was 34.8 million m^3, and 9.7 million m^3, respectively—the largest amount for any single pest. The budworm has not been as prominent in western Canada as in the east. Cerezke (1978a) suggested this is because outbreaks do not tend to be as frequent, extensive, or severe, and they often occur in isolated areas. Despite the fact that the insect prefers balsam fir as a host in eastern North America, several outbreaks have occurred in the prairie provinces and the Northwest Territories in white spruce stands containing little or no balsam fir (Ives and Wong 1988). Balsam fir is more susceptible to damage than white or black spruce (Ives and Wong 1988).

In the Northwest Region, outbreaks of the budworm have been recorded (intermittently at first) since 1907 (Hewitt 1911). Beginning in the early 1950s, they have been monitored annually by air and ground surveys by the Forest Insect and Disease Survey and provincial agencies. Areas of major infestation have been mapped and the intensity of defoliation rated into the broad categories of light (<30%), moderate (30–60%) and severe (≥60% defoliation of the current years foliage). Historically, outbreaks in Manitoba and Saskatchewan have occurred within the southern two-thirds of the provinces (Hildahl and DeBoo 1973; Ives 1969). In Alberta, all major outbreaks, with the exception of the Cypress Hills area, have occurred north of 56° latitude, and as is the case in the Northwest Territories nearly all outbreaks were confined to major river valleys (Cerezke 1978a).

Growth Loss

Repeated defoliation by the spruce budworm leads to a gradual diminishing tree height and diameter growth. Losses in radial increment of white spruce usually appear in the lower stem 2–4

years after the start of an infestation, and may continue for 1–3 years after the collapse of the outbreak (Cerezke 1978a). Reductions of 50% or more of the normal increment of white spruce may be common (Stevenson 1970; Cerezke 1976; Cerezke 1978a), while for balsam fir reductions of 50–75% can be expected (MacLean 1985).

Examples from the Northwest Region include the work of Cerezke (1976) in northern Alberta, where 30–50% reductions in radial increment of white spruce occurred from 2 to 4 years after the start of an outbreak and extended a few years after its termination. He based his growth figures on the measurement of annual rings on disks removed from the upper crown and dbh levels of study trees, and attempted to tabulate the effects of defoliation and precipitation separately. Cerezke concluded that growth loss due to defoliation was most prominent in the upper crowns of study trees, and that growth at dbh may be more sensitive to moisture availability than defoliation. Tripp et al. (1970) suggested that growth reductions for defoliated white spruce in northern Alberta may be as much as 50–70%.

In Manitoba and Saskatchewan, after 8–10 years of moderate-to-severe defoliation during the Namew Lake outbreak (1951–68), radial growth losses of 30–50% of white spruce occurred for several years (Cerezke 1978a). Also in Manitoba, Wotton and Jones (1976a) studied spruce budworm caused damage in white spruce stands in the Spruce Woods Provincial Park and forest. Radial growth at dbh was examined on twenty-two 32- to 90-year-old white spruce trees. The results indicated 4 infestation periods; the first continuous growth suppression took place between 1929 and 1940 (with a slight upsurge in 1935); the second occurred in 1945 for 7 years; the third occurred in 1956 for 6 years; and, the last infestation was from 1971 to 1975. The maximum annual percentage reductions in radial increment were: 1934 (37%); 1951 (41%); 1961 (38%); and in 1975 (48%). This varied with age and declining growth increment as the tree approached maturity. The average duration of radial suppression was 8 years and the average interim period of recovery was 6 years (Wotton and Jones 1976a). Wotton and Jones did not examine weather records prior to making their conclusions nor did they match these periods with known outbreaks; consequently, other influences such as drought cannot be discounted.

In Ontario, Gross (1985) based growth loss impact by spruce budworm on data reported by Kulman (1971). Regression models were fitted to data and the percentage growth reduction by number of years defoliated at the moderate-to-severe level of damage was determined for balsam fir and white and black spruce (Table 4). Summaries of studies of loss of radial and volume increment of spruce and fir resulting from defoliation by the spruce budworm elsewhere in North America can be found in MacLean. Many of the points MacLean makes are relevant to the Northwest Region. In general, the studies documented a gradual decrease in growth (more pronounced for balsam fir than white spruce) with the length of time trees were moderately to severely defoliated. Reductions in radial increment were greatest at midcrown and least near the crown base; and the magnitude of growth losses were related to the severity and temporal sequence of defoliation. Height growth often ceased during periods of severe defoliation and possibly declined due to top kill.

Tree Mortality and Top Kill

The inevitable consequence of spruce budworm defoliation, which is both prolonged and severe is the mortality of a certain percentage of trees in affected stands. The onset of tree mortality depends on the defoliation history and varies with tree species, vigor, age, and stand density; trees in suppressed and intermediate crown classes are the first to die (Witter et al. 1984). Some dominant and codominant balsam fir will die after about five years of repeated severe defoliation of the current year's growth (Witter et al. 1984). Given the same conditions, white spruce will begin to die in 5–7 years (Cerezke 1978a; Witter et al. 1984). Top kill

Table 4. Reduced growth rate associated with spruce budworm defoliation in Ontario (after Gross 1985)

Years of moderate-to-severe defoliation	Reduction in growth rate	
	Black and white spruce	Balsam fir
1	0.22	0.00
2	0.31	0.18
3	0.40	0.35
4	0.50	0.57
5	0.60	0.81
6	0.70	0.91
7	0.78	1.00

precedes mortality and is most common in understory trees (Cerezke 1976; Stevenson 1970) and is directly related to larval population size (Cerezke 1978a). Top kill leads to deformities and can be an entry point for decay fungi and insects (Basham 1984; MacLean 1985). Basham (1984) reported that the fungi and insects that colonize dead tree tops seldom descend into the merchantable stem portions.

Regional examples include the results of a damage appraisal survey of dominant and codominant white spruce in the Wabasca River (Alberta) area in 1962, (conducted over 31 km^2). After at least ten years of defoliation, the incidence of white spruce mortality was 6% and top kill 23% (Brown 1963; Cerezke 1978a). Plot studies in the same area revealed that by 1968 tree mortality was 39%, and 44% of the live trees had dead tops (Table 5). Merchantable volume losses were estimated to be between 10 and 50% (Stevenson 1970).

In Manitoba and Saskatchewan, after 8–10 years of heavy defoliation during the Namew Lake outbreak (1951–68), spruce–fir forests within a total area of 650 km^2 showed white spruce and balsam fir mortality rates of 30 and 40%, respectively. Additional losses included a high percentage of the remaining trees with dead tops (Cerezke 1978a).

An eastern Manitoba outbreak (1954–60) resulted in 20% mortality of merchantable white spruce and over 65% mortality of balsam fir over about 260 km^2 of forest (Cerezke 1978a). An outbreak in the Spruce Woods Forest Reserve covered 298 km^2 in 1973 and caused almost total mortality of white spruce regeneration in some areas.

In Manitoba, discontinuous stands of pure white spruce in the Spruce Woods Provincial Forest and Park were assessed for past, current, and future tolerance to spruce budworm attack (Wotton and Jones 1976b). Defoliation and mortality surveys in 10 variable radius plots in each of treated and untreated areas indicated that a 1973 pesticide application did not provide any measurable reduction in severity of damage three years after spraying. Results of the 1976 defoliation and mortality surveys are presented in Table 6.

Annual reports of the forest insect and disease survey from 1963 to 1966 provide insight into the progression of damage caused by the spruce budworm during persistent infestations in the Northwest Territories. Brown and Stevenson (1964) examined evidence from tree rings and suggested that an infestation on Long Island in the Slave River may have been present for 25 years. They estimated that in 1963, 30–40% of the white spruce on the southern half of the island had died as a result of budworm activity. In 1965, top kill of live white spruce on the southern half of Long Island was estimated at 68%, and was 25% on plots at Grand Detour, which is also on the Slave River (Baranyay and Stevenson 1966). Defoliation in the Slave River valley in 1966 was light and trees still alive after suffering a number of consecutive years of severe defoliation exhibited a remarkable ability to recover (Tripp et al. 1967). A second consecutive year of light defoliation occurred on Long Island in 1967. Remeasurement of impact plots in that year revealed white spruce mortality to be 77% and top kill 16% (Tripp and Robins 1968). Other data gleaned from annual survey reports indicated mortality rates of 57% and 31% at Redstone River and near Old Fort Point, respectively, on the Mackenzie River (Brown and Stevenson 1965), and tree mortality of 30% and top kill of 60% at the confluence of the Blackwater and Mackenzie rivers (Tripp and Robins 1968).

Table 5. White spruce mortality and top kill caused by the spruce budworm in northern Alberta (1959–68) (Stevenson 1970)

Year	Total trees	% mortality dominant and codominant	% live trees with dead tops
1962	174	5.0	18.0
1965	190	6.3	18.9
1967	304	34.0	49.0
1968	383	39.0	44.0

Table 6. Summary of spruce budworm damage following control trials in the Spruce Woods Provincial Forest and Park, Manitoba (after Wotton and Jones 1976b)

Sampling levels	Treated		Untreated	
	No. trees	% trees	No. trees	% trees
Sample size	138	100	112	100
Top kill	49	36	51	46
Dead	8	6	5	4

The relationship between successive years defoliation of spruce/fir stands by the spruce budworm and mortality to white spruce and balsam fir was investigated by Howse et al. (1981) in Ontario. Their data was summarized by Gross (1985), and they indicate that mortality of the balsam fir component occurs earlier in the outbreak and is more severe than that of white spruce (Table 7).

Quality Reductions Following Mortality

The preceding discussion clearly illustrates that spruce budworm defoliation can lead to extensive areas of dead timber, which raises questions regarding the utilization of this material. Basham (1984) reviewed this subject and the relevant findings of his work will be addressed. The majority of the material he examined dealt with balsam fir in eastern North America. There are two main factors to consider in utilizing timber from stands severely impacted by the spruce budworm. Firstly, stands with a high proportion of dead trees present a greater safety hazard than healthy stands. This aspect will not be addressed in this report. Secondly, the degradation and loss of wood fiber in recently killed material must be discussed. It may be appropriate to preface the discussion by saying that Basham (1984) doubted that it would be possible to prepare a precise straight-forward manual on the rate of deterioration of budworm-killed trees because of the number of variables involved. He did state that there are three significant changes in tree stems as they pass from a moribund to a dead state: they become dry and brittle; they are invaded by wood-consuming insects; and they are invaded by the principle agents of deterioration (fungi). Fungal deterioration can seriously affect the yield and quality of pulp and paper from budworm-killed trees, with losses increasing with the length of time since tree death (Basham 1984). Basham referred to a study that showed that lumber from spruce defoliated or killed by the spruce budworm had defects that degraded 40% of the volume resulting in a 21% drop in product value. It has been suggested that balsam fir be harvested within a year after death if lumber is the intended product. Budworm-killed spruce and balsam fir can be used to make an acceptable quality waferboard, with wafer yield decreasing with the passage of time (Basham 1984).

Table 7. The percentage of volume rated as dead associated with the number of years that mortality caused by spruce budworm had been present in fir/spruce stands in northern Ontario (Gross 1985)

Years mortality	Balsam fir	White spruce
1	5.0	0.0
2	20.0	0.0
3	35.7	8.1
4	52.5	15.5
5	75.0	26.6
6	82.5	30.2
7	90.0	33.9
8	95.0	36.4
9	97.0	37.3

JACK PINE BUDWORM

The jack pine budworm (*Choristoneura pinus* Freeman) has long been a serious pest of jack pine stands in Manitoba and Saskatchewan. Since records have been kept, there have been periodic buildups of budworm numbers to outbreak levels over large areas, followed by dramatic population reductions (Moody 1986; Volney 1988). Volney (1988) analyzed jack pine budworm outbreaks in Saskatchewan and Manitoba over a 50 year period. He concluded the area affected appeared to be increasing; population increases seemed to follow periods of heavy fire activity by 20–30 years; and both budworm outbreaks and heavy fire activity reoccur about every 10 years. There were no reports of outbreaks of this budworm in Alberta until 1985 when moderate defoliation was recorded by Forestry Canada's Forest Insect and Disease Survey in small isolated stands of jack pine in central

Alberta (Moody and Cerezke 1986). This outbreak has remained confined to these stands.

Outbreaks in Manitoba have been of longer duration and have resulted in more damage than in Saskatchewan (Moody 1986). Records (Table 8) indicate the outbreaks were of variable duration and occurred over short intervals. Brandt and McDowall (1968) linked the persistence of outbreaks to the parasitism rate of budworm, host tree condition (especially the density of staminate flowers), and weather. Most outbreaks lasted 2–5 years, and some caused moderate-to-severe defoliation over many thousands of hectares of jack pine forests (Moody 1986); however, localized areas of light-to-moderate defoliation were also characteristic of most intervening years. Detailed cartographic histories of the jack pine budworm in Manitoba and Saskatchewan from 1938 to 1967 were given by Brandt and McDowall (1968).

Defoliation by the jack pine budworm spreads from the top of the tree crown downwards (DeBoo and Hildahl 1968). Consequently, top kill and reduced annual growth are the most common losses (Moody 1986). Tree mortality, however, can occur after 2 or more years of severe defoliation, especially on poor sites. Extensive top kill, reduced radial growth, and tree mortality have been reported in Canada by Brandt and McDowall (1968), Cerezke (1978b, 1986), DeBoo and Hildahl (1968), and Howse (1984).

Growth Loss

Cerezke (1986) studied the impact of the jack pine budworm in 6 plots in a 50 to 55-year-old stand in the Nisbet Provincial Forest during an outbreak that lasted from 1975 to 1978. Eight disks were cut from the main stem (two trees per plot), starting at one meter below the apex and at one meter intervals to the base of the crown, and one disk at breast height. These served to obtain radial growth profile patterns, vertically and horizontally, within the stem. The results indicated that radial growth was significantly reduced throughout the stem in 1977 and 1978, and additional losses probably continued for at least two postoutbreak years. Volume growth, estimated for each of the four outbreak years was compared with the mean annual increment volume for the five previous (nonoutbreak) years, and indicated reductions of up to 47 and 91%, respectively for the 1977 and 1978 increments.

The losses estimated by Cerezke (1986) are compatible with those in Minnesota, where new and old foliage losses were recorded separately from cross sections cut at 1.5-m intervals from the base to the top of trees (Kulman 1971; Kulman et al. 1963). The budworm feeds on new foliage first, and it was assumed that its loss would have a greater effect on tree growth (relative to the loss of old foliage). Springwood and summerwood were measured separately, and growth rates for trees experiencing various levels of defoliation in 1956 were compared to the previous two (nondefoliated) years to estimate growth reductions. Springwood of the defoliation year (1956) was not affected, but 1956 summerwood ring and both springwood and summerwood rings in 1957 and 1958 were reduced proportionately to the severity of the 1956 defoliation (Table 9). By 1958 only trees that were heavily and very heavily defoliated in 1956 were still experiencing reduced growth (Kulman et al 1963). The 2-year cumulative volume increment of trees, which were moderately defoliated for a single season by the jack pine budworm, was 55–65% of trees that only received light defoliation (Jacquith et al. 1958).

Wotton et al. (1978) assessed the effectiveness of a control treatment in preventing damage by the jack pine budworm. The treatment was an aerial application of fenitrothion (292 mL/ha) to stands in the Bélair Provincial Forest in 1977. Sampling was done on 5 transects, each with two plots at 100 m intervals in both the treated (Stead area) and untreated stands (Bélair area). All plot trees over 9.0 cm dbh were measured and assessed for degree of defoliation damage using a 5 point indexing scheme (Table 10). Table 10 also includes a percent potential volume increment loss associated with each defoliation index class. These were determined from previously reported patterns of radial increment loss in the study areas and provided a basis for predicting increment loss based on severity of defoliation during the treatment efficiency assessment (Wotten et al. 1978).

The total number of trees sampled at Stead was 149 with a mean height of 13.9 m, mean dbh of 17.54 cm, and mean age of 52 years. In Bélair there were 94 trees sampled with a mean height of 11.52 m, dbh of 17.62 cm and a mean age of 50 years. Radial increment analysis of disks taken at breast height presented 4 distinct suppression periods, 1949, 1954, 1961, and 1964. These periods can be associated with increased levels of jack pine budworm infestations substantiated by documented

Table 8. Chronological bibliographic citations of reports pertaining to forest insect and disease conditions in the prairie provinces and the Northwest Territories, 1937-88 (compiled by W.J.A. Volney and M.S. Mason)

Department of Agriculture. 1959. The insect survey in 1936. *In* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for all jurisdictions.)

Brown, A.W.A. 1959a. The forest insect survey, 1937. Report of the Ottawa Section. Pages 13–20 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for Manitoba and Saskatchewan.)

Brown, A.W.A. 1959b. The forest insect survey 1938. Summary report of the Ottawa Section. Pages 36–48 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for Manitoba and Saskatchewan.)

Hopping, R. 1959. The forest insect survey, 1937. Summary report of the 1937 forest insect survey in British Columbia. Pages 26–34 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Dep. Agric., Ottawa, Ontario. (Material for Rocky Mountain national parks in Alberta.)

Hopping, R.; Leech, H.B. 1959. The forest insect survey 1938. Summary report of British Columbia Section. Pages 53–55 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for Rocky Mountain national parks in Alberta.)

Brown, A.W.A. 1940. Annual report of the forest insect survey 1939. Pages 5–30 *in* Annual report of the forest insect survey 1939. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for all jurisdictions.)

Brown, A.W.A. 1941. Annual report of the forest insect survey. Pages 5–27 *in* Annual report of the forest insect survey, forest insect investigations, 1940. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for all jurisdictions.)

Brown, A.W.A. 1942. Annual report of the forest insect survey 1941. Pages 3–23 *in* Annual report of the forest insect survey, forest insect investigations, 1941. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for all jurisdictions.)

Brown, A.W.A. 1943. Annual report of the forest insect survey, 1942. *In* Annual report of the forest insect survey, forest insect investigations, 1942. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Material for all jurisdictions.)

Richmond, H.A.; Smith, D.N. 1944. Summary report of the forest insect survey, forest area prairie provinces and far western Ontario. Pages 46–55 *in* Annual report of the forest insect survey, forest insect investigations, 1943. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L. 1944. Summary report of the forest insect survey, agricultural area, prairie provinces. Pages 56–61 *in* Annual report of the forest insect survey, forest insect investigations, 1943. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1944. Summary report of forest survey, British Columbia and western Alberta. Pages 62–68 *in* Annual report of the forest insect survey, forest insect investigations, 1943. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Richmond, H.A.; McGuffin, W.C. 1945. Summary report of the forest insect survey, central Canada. Pages 40–51 *in* Annual report of the forest insect survey, forest insect investigations, 1944. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L.O.T. 1945. Summary report of the forest insect survey, agricultural area, prairie provinces. Pages 52–61 *in* Annual report of the forest insect survey, forest insect investigations, 1944. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1945. Summary report of the forest insect survey, British Columbia and Rocky Mountain national parks. Pages 62–70 *in* Annual report of the forest insect survey, forest insect investigations, 1944. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Lejeune, R.R. 1946. Prairie provinces forested area. Pages 43–52 *in* Annual report of the forest insect survey, forest insect investigations, 1945. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L.O.T 1946. Prairie provinces agricultural area. Pages 53–60 *in* Annual report of the forest insect survey, forest insect investigations, 1945. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1946. British Columbia and Rocky Mountain national parks. Pages 61–67 *in* Annual report of the forest insect survey, forest insect investigations, 1945. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C.; Barker, R.B. 1947. Prairie provinces forested area. Pages 54–65 *in* Annual report of the forest insect survey, forest insect investigations, 1946. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L.O.T.; Sandercock, E.M. 1947. Prairie provinces agricultural area. Pages 66–76 *in* Annual report of the forest insect survey, forest insect investigations, 1946. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1947. British Columbia and Rocky Mountain national parks. Pages 77–86 *in* Annual report of the forest insect survey, forest insect investigations, 1946. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Table 8. Continued

Barker, R.B.; Wong, H.R. 1948. Prairie provinces forested area. Pages 64–79 *in* Annual report of the forest insect survey, forest insect investigations, 1947. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

MacKay, M.R. 1948. British Columbia and Rocky Mountain national parks. Pages 91–102 *in* Annual report of the forest insect survey, forest insect investigations, 1947. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Barker, R. 1949. Provinces of Manitoba and Saskatchewan forested area. Pages 73–89 *in* Annual report of the forest insect survey, forest insect investigations, 1948. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Sandercock, E.M.; Cumming, M.E.P. 1949. Prairie provinces agricultural area. Pages 90–101 *in* Annual report of the forest insect survey, forest insect investigations, 1948. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1949. Alberta and Rocky Mountain national parks. Pages 102–109 *in* Annual report of the forest insect survey, forest insect investigations, 1948. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wong, H.R.; Smith, J.D.; Hildahl, V. 1950. Provinces of Manitoba and Saskatchewan forested area. Pages 70–84 *in* Annual report of the forest insect survey, forest insect investigations, 1949. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1950. Prairie provinces agricultural area. Pages 85–96 *in* Annual report of the forest insect survey, forest insect investigations, 1949. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1950. Alberta and Rocky Mountain national parks. Pages 97–104 *in* Annual report of the forest insect survey, forest insect investigations, 1949. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wong, H.R.; Turnock, W.J.; Hildahl, V. 1951. Provinces of Manitoba and Saskatchewan forested area. Pages 69–82 *in* Annual report of the forest insect survey 1950. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1951. Prairie provinces agricultural area. Pages 83–95 *in* Annual report of the forest insect survey 1950. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C.; Reid, R.W. 1951. Alberta and Rocky Mountain national parks. Pages 96–105 *in* Annual report of the forest insect survey 1950. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wong, H.R.; Hildahl, V.; Prentice, R.M. 1952. Provinces of Manitoba and Saskatchewan forested area. Pages 66–82 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Forest insect survey.)

Brown, C.E.; Cumming, M.E.P. 1952. Prairie provinces agricultural area. Pages 83–93 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Forest insect survey.)

McGuffin, W.C.; Reid, R.W. 1952. Alberta and Rocky Mountain national parks. Pages 94–103 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Forest insect survey.)

Riley, C.G.; Denyer, W.B.; Whitney, R.D. 1952. Prairie provinces. Pages 140–146 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario. (Forest disease survey from 1948 to 1951.)

Wong, H.R.; Prentice, R.M.; Hildahl, V. 1953. Prairie provinces forest insect survey, provinces of Manitoba and Saskatchewan forest area. Pages 79–91 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Thomas, R.W. 1953. Forest disease survey, provinces of Manitoba and Saskatchewan forest area. Pages 92–99 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1953. Forest insect survey, agricultural area. Pages 100–111 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1953. Forest insect survey, Alberta, Rocky Mountain national parks, and Northwest Territories. Pages 112–120 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1953. Forest disease survey, Alberta and Rocky Mountain national parks. Pages 121–126 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1954a. Prairie provinces, provinces of Manitoba and Saskatchewan forested area forest insect survey. Pages 91–103 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Thomas, R.W. 1954. Prairie provinces, provinces of Manitoba and Saskatchewan forest disease survey. Pages 104–111 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1954. Prairie provinces agricultural area forest insect survey. Pages 112–120 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1954. Prairie provinces, Alberta and Rocky Mountain national parks forest insect survey. Pages 121–127 *in* Annual report of the forest insect and disease survey

Table 8. Continued

1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1954a. Prairie provinces, Alberta and Rocky Mountain national parks forest disease survey. Pages 128–135 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Sandercock, E.M.; Peterson, L.O.T. 1948. Prairie provinces agricultural area. Pages 80–90 *in* Annual report of the forest insect survey, forest insect investigations, 1947. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1954b. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 82–96 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1954. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 97–101 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; McGuffin, W.C. 1954. Province of Alberta forest insect survey. Pages 102–107 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1954b. Province of Alberta forest disease survey. Pages 108–114 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1956. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 70–81 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1956. Provinces of Manitoba and Saskatchewan forest disease survey. Page 82 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; Robins, J.K. 1956. Province of Alberta forest insect survey. Pages 83–88 *in* Annual report of the forest insect and disease survey 1955 For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1956. Province of Alberta forest disease survey. Pages 89–91 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1957. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 60–70 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. of Agric., Ottawa, Ontario.

Zalasky, H.; Riley, C.G. 1957. Provinces of Manitoba and Saskatchewan forest disease survey. Page 71 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; Robins, J.K. 1957. Province of Alberta forest insect survey. Pages 72–76 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1957. Province of Alberta forest disease survey. Pages 77–78 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1958. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 53–64 *in* Annual report of the forest insect and disease survey 1957. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; Robins, J.K. 1958. Province of Alberta forest insect survey. Pages 65–69 *in* Annual report of the forest insect and disease survey 1957. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Loman, A.A. 1958. Province of Alberta forest disease survey. Pages 70–71 *in* Annual report of the forest insect and disease survey 1957. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1959. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 62–71 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1959. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 72–73 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Hopkins, M.C.; Robins, J.K. 1959. Province of Alberta forest insect survey. Pages 74–80 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Loman, A.A.; Bourchier, R.J. 1959. Province of Alberta forest disease survey. Pages 81–83 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1960. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 68–78 *in* Annual report of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1960. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 79–80 *in* Annual report of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Hopkins, M.C.; Robins, J.K. 1960. Province of Alberta forest insect survey. Pages 81–87 *in* Annual report

Table 8. Continued

of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Thomas, G.P.; Bourchier, R.J.; Loman, A.A. 1960. Province of Alberta forest disease survey. Pages 88–92 *in* Annual report of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1961. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 68–77 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Zalasky, H. 1961. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 78–80 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Robins, J.K.; Stevenson, R.E. 1961. Province of Alberta forest insect survey. Pages 81–87 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A.; Bourchier, R.J. 1961. Province of Alberta forest disease survey. Pages 88–92 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1962. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 77–89 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Riley, C.G.; Zalasky, H. 1962. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 92–101 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Robins, J.K.; Stevenson, R.E. 1962. Province of Alberta forest insect survey. Pages 92–101 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A.; Bourchier, R.J.; Stevenson, G.R. 1962. Province of Alberta forest disease survey. Pages 102–106 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1963. Manitoba and Saskatchewan forest insect and disease survey. Page 77 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1963. Forest insect conditions. Pages 78–85 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Riley, C.G.; Hildahl, V. 1963. Forest disease conditions. Pages 86–90 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1963. Alberta forest insect and disease survey. Pages 91–92 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Stevenson, R.E. 1963. Forest insect conditions. Pages 92–98 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A.; Bourchier, R.J. 1963. Forest disease conditions. Pages 99–105 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1964. Manitoba and Saskatchewan forest insect and disease survey. Pages 75–76 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1964. Forest insect conditions. Pages 76–85 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Riley, C.G.; Hildahl, V. 1964. Forest disease conditions. Pages 85–94 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1964. Province of Alberta forest insect and disease survey. Pages 95–96 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Stevenson, R.E. 1964. Forest insect conditions. Pages 96–101 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A. 1964. Forest disease conditions. Pages 102–108 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1965. Manitoba and Saskatchewan forest insect and disease survey. Pages 78–79 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1965. Forest insect conditions. Pages 79–89 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Laut, J.G.; Hildahl, V. 1965. Forest disease conditions. Pages 90–95 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Table 8. Continued

Department of Forestry. 1965. Province of Alberta forest insect and disease survey. Pages 96–97 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Stevenson, R.E. 1965. Forest insect conditions. Pages 97–102 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A. 1965. Forest disease conditions. Pages 102–110 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Laut, J.G. 1966. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 66–80 *in* Annual report of the forest insect and disease survey 1965. Dep. For., Ottawa, Ontario.

Baranyay, J.A.; Stevenson, R.E. 1966. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 81–92 *in* Annual report of the forest insect and disease survey 1965. Dep. For., Ottawa, Ontario.

Elliott, K.R.; Laut, J.G.; Brandt, N.R. 1967. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 75–94 *in* Annual report of the forest insect and disease survey 1966. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Tripp, H.A.; Stevenson, R.E.; Baranyay, J.A. 1967. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 95–107 *in* Annual report of the forest insect and disease survey 1966. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Ives, W.G.H.; Brandt, N.R.; Sutton, B.C. 1968. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 76–96 *in* Annual report of the forest insect and disease survey 1967. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Tripp, H.A.; Robins, J.K. 1968. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 97–107 *in* Annual report of the forest insect and disease survey 1967. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Ives, W.G.H.; Brandt, N.R.; Lawrence, J.J. 1969. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 79–97 *in* Annual report of the forest insect and disease survey 1968. Can. Dep. Fish. For., For. Branch, Ottawa, Ontario.

Tripp, H.A.; Blauel, R.A. 1969. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 98–110 *in* Annual report of the forest insect and disease survey 1968. Can. Dep. Fish. For., For. Branch, Ottawa, Ontario.

Ives, W.G.H.; Brandt, N.R.; Laut, J.G. 1970. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 72–83 *in* Annual report of the forest insect and disease survey 1969. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario.

Tripp, H.A.; Robins, J.K.; Blauel, R.A. 1970. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 84–96 *in* Annual report of the forest insect and disease survey 1969. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Blauel, R.A.; Robins, J.K. 1971. Prairies region. Important forest insects. Important forest diseases. Pages 67–76 *in* Annual report of the forest insect and disease survey 1970. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Blauel, R.A.; Robins, J.K. 1972. Prairies region. Important forest insects. Important forest diseases. Pages 73–80 *in* Annual report of the forest insect and disease survey, 1971. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Lawrence, J.J.; Robins, J.K. 1973. Prairies region. Important forest insects. Important forest diseases. Pages 74–81 *in* Annual report of the forest insect and disease survey, 1972. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Lawrence, J.J.; Robins, J.K. 1974. Prairies region. Important forest insects. Important forest diseases. Pages 70–77 *in* Annual report of the forest insect and disease survey, 1973. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Lawrence, J.J.; Petty, J., Robins, J.K. 1975. Prairies region. Important forest insects. Important forest diseases. Pages 75–81 *in* Annual report of the forest insect and disease survey, 1974. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Petty, J. 1976. Prairie region. Important forest insects. Important forest diseases. Pages 69–74 *in* Annual report of the forest insect and disease survey, 1975. Fish. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Petty, J. 1979. Prairie region. Important forest insects. Important forest diseases. Pages 71–75 *in* Annual report of the forest insect and disease survey, 1976. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Hiratsuka, Y.; Petty, J. 1981. Prairies region. Important forest insects. Important forest diseases. Pages 71–79 *in* Annual report of the forest insect and disease survey, 1977. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Hiratsuka, Y.; Petty, J. 1982. Prairies region. Important forest insects. Important forest diseases. Pages 55–61 *in* Annual report of the forest insect and disease survey 1978 and 1979.

Table 8. Concluded

Annual report 1978. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Hiratsuka, Y.; Cerezke, H.F.; Petty, J. 1982. Prairies region. Important forest insects. Important forest diseases. Pages 59–69 *in* Annual reports of the forest insect and disease survey 1978 and 1979. Annual report 1979. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Sterner, T.E.; Davidson, A.G., compilers. 1981. Forest insect and disease conditions in Canada 1980. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Sterner, T.E.; Davidson, A.G., compilers. 1982. Forest insect and disease conditions in Canada 1981. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Sterner, T.E.; Davidson, A.G., compilers. 1983. Forest insect and disease conditions in Canada 1982. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Taylor, R.G.; compilers. 1984. Forest insect and disease conditions in Canada 1983. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Taylor, R.G.; compilers. 1985. Forest insect and disease conditions in Canada 1984. Forest insect and disease survey. Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Taylor, R.G.; compilers. 1986. Forest insect and disease conditions in Canada 1985. Forest insect and disease survey. Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Moody, B.H.; compilers. 1987. Forest insect and disease conditions in Canada 1986. Forest insect and disease survey. Can. For. Serv., Ottawa, Ontario.

Moody, B.H.; compiler. 1988. Forest insect and disease conditions in Canada 1987. Forest insect and disease survey. For. Can., Petawawa Nat. For. Inst., Chalk River, Ontario. (Includes supplement.)

Moody, B.H.; compiler. 1990. Forest insect and disease conditions in Canada 1988. Forest insect and disease survey. For. Can., Petawawa Nat. For. Inst., Chalk River, Ontario.

Table 9. Percent reduction in average ring growth area in jack pine resulting from various levels of defoliation in 1956 in Minnesota (after Kulman et al. 1963)

Defoliation class	% reduction					
	Springwood			Summerwood		
	1956	1957	1958	1956	1957	1958
Light (25–75%)	0	54	8	32	27	0
Medium (76–100%)	0	76	1	60	44	0
Heavy[a]	0	99	52	83	73	20
Very heavy[b]	0	99	86	99	91	86

[a] Heavy = 100% current and 26–75% old needles consumed.

[b] Very heavy = 100% current and 76–100% old needles consumed.

Table 10. Jack pine budworm defoliation damage indexes and potential volume loss indexes used during the Bélair Provincial Forest control trial (Wotton et al. 1978)

Defoliation index	Crown description	% potential volume increment loss
0–1	Full vigorous crown, no evidence of defoliation	0
1.1–2.0	Crown healthy but thinning, some evidence of defoliation	26.0–50.0
2.1–3.0	Moderate crown vigor, marked evidence of defoliation	51.0–75.0
3.1–4.0	Significant decline in crown vigor, severe defoliation	76.0–99.0
4.1–5.0	Dead	100

reports of the Forest Insect and Disease Survey (Table 8). At least one infestation (1961) coincides with a period of elevated forest fire activity, which would suggest drought conditions (Volney 1988).

Table 11 presents a summary of mean defoliation indexes, potential radial increment, potential volume increment, and percent potential volume increment loss for the Bélair and Stead study areas for each of the 1976–78 assessment periods (Wotton et al. 1978). The authors concluded that any gains in increment due to the treatment were confined to the year the area was sprayed and the one year following spraying. The ages of the stands affected the growth, which was quite slow, and it was concluded that the treatment preserved only 0.00403 m^3/ha of increment during the 1977, and 0.00207 m^3/ha during the 1978 growing seasons.

Tree Mortality and Top Kill

Moody (1986) summarized the history of jack pine budworm outbreaks in Saskatchewan and could not find references to top kill and mortality prior to the late 1970s. A major outbreak from 1976 to 1979 in the Nisbet Provincial Forest caused a 20–30% incidence of top kill in 1978 in some areas, but tree mortality that could be attributed to budworm defoliation was considered insignificant (Hiratsuka et al. 1981). The work of Cerezke (1986) concurred as he showed top kill to be variable but present in the Nisbet Forest during 1976, 1977, and 1978. Visual inspection in 1978 indicated that top kill of 0.2–0.5 m was evident on an average of 20% of all trees (range: 10–50%). No tree mortality was observed that could be attributed solely to budworm defoliation.

In Manitoba, considerable data on budworm damage has been accumulated from early infestations that indicate the seriousness of repeated jack pine budworm defoliation (Brandt and McDowall 1968). In 1944, jack pine stands in the Sandilands Provincial Forest suffered a 12–60% incidence of top kill (1–2.5 m in length); and an additional 6% top kill in 1947. In 1949, jack pine stands near Gypsumville were cruised in strips 10 m wide by 200 m long positioned every 200 m throughout the stand. Each tree was tallied in 2.5 cm diameter classes from 1.3 to 25.4 cm dbh, and by percent defoliation of current foliage and old needles. The survey indicated an average of 10% mortality of jack pine occurring mostly in the smallest trees (Table 12). Mortality was most common in the suppressed crown class and lightest in the dominant classes. Similar cruises were carried out in the Sandilands Provincial Forest in 1956. The results are shown in Table 13. Calculations indicate a maximum loss of 11.09% in the basal area of a stand (Brandt and McDowall 1968).

In Ontario, Howse (1984) reported that damage is seldom quantified except in very general or broad terms. In 1971, fully stocked stands of pole-sized jack pine on generally good sites near Lake Traverse, Algonquin Park District, suffered 25% mortality and 30% top kill following light defoliation in 1967 and moderate-to-severe defoliation in 1968 and 1969. The infestation collapsed in 1970. More severe damage can occur in low-density stands of large-crowned, flowering trees or in intermediate or suppressed trees of low vigor.

In Minnesota, medium and heavy defoliation in a young pole-sized stand caused 2–6% mortality in dominant and codominant trees and 9–13% in

Table 11. Summary of defoliation impact as related to volume loss during Bélair Provincial Forest control trial (after Wotton et al. 1978)

Growth parameters	1976 prespray		1977 sprayed		1978 postspray	
	Bélair	Stead	Bélair	Stead	Bélair	Stead
Mean defoliation category	2.01	2.12	2.35	1.74	2.03	1.71
Potential radial increment (mm)	1.41	0.69	1.39	0.65	1.38	0.61
Volume potential increment (m^3/ha)	0.056	0.026	0.054	0.012	0.053	0.020
Percent potential volume increment loss	48.8	51.5	57.1	41.1	49.3	40.4

Table 12. Jack pine budworm caused defoliation and mortality of jack pine in the Gypsumville area, Manitoba in 1949 (after Brandt and McDowall 1968)

Cruise strip number	Total no. trees	Mean dbh (cm)	Defoliation class %		% dead trees
			New foliage	Old foliage	
1	161	13.5	76–100	76–100	18.0
2	197	12.9	76–100	76–100	17.2
3	147	14.2	76–100	76–100	12.6
4	167	10.7	26–50	0–25	0.6
5	93	12.7	0–25	0–25	7.5
6	150	15.2	76–100	76–100	6.7
7	123	14.0	0–25	0–25	6.5
8	71	16.0	76–100	76–100	5.6
9	124	14.2	76–100	76–100	12.9

Table 13. The loss of basal area attributable to jack pine budworm defoliation in Sandilands Provincial Forest 1956 (after Brandt and McDowall 1968)

Cruise line defoliation history[a]	Dbh (cm)			Stand basal area	
	Mean	Minimum	Maximum	Total (m^3/ha)	% loss
O–O–L	9.1	2.5	25.4	14.4	0.5
O–M–S	9.6	2.5	25.4	20.2	1.5
L–M–M/S	10.8	2.5	33.0	13.2	4.2
L–M–S	5.7	2.5	27.9	18.9	7.4
L–M/S–S	8.3	2.5	33.0	14.8	11.1

[a] Defoliation is represented by a sequence of 3 codes, separated by dashes, for 1954, 1955, and 1956, respectively. O = no, L = light, M = moderate, S = severe, and M/S = moderate-to-severe defoliation.

codominant and intermediate trees during the first two years after defoliation. Twenty-nine to 44% of almost completely defoliated trees died (Kulman et al. 1963). Mortality was as high as 87% for suppressed trees that were very heavily defoliated.

Jack pine budworm can also cause serious damage to red pine when associated with jack pine (Kulman and Hodson 1961). The authors concluded that survival of the insect on either host is associated with the presence of staminate cones, and that red pine may serve to maintain populations at subepidemic levels between periods of staminate cone production on jack pine. Kulman and Hodson (1961) went on to document incidences of top kill of red pine in all crown classes following jack pine budworm defoliation in mixed red and jack pine stands in Minnesota.

MOUNTAIN PINE BEETLE AND BLUE STAIN FUNGI

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the most destructive forest insect pest that attacks mature lodgepole and other pine forests in western Canada (Ives and Wong 1988). This beetle has caused significant losses in Alberta by killing the biggest trees in stands of lodgepole

pine, often reducing the amount of merchantable timber to the point that harvesting residual trees is unprofitable (Alberta Forest Service 1986). Winter temperatures in Alberta were thought to be too extreme for the beetle to become a major problem, but recent events have disproven this opinion (Ives and Wong 1988). Trees are killed by girdling caused by beetle feeding and boring and by the presence of blue stain fungi (*Ceratocystis* spp.), which blocks water transport in the main stem (Hiratsuka 1987). The insect transmits the fungus into the trees in which they colonize.

The first documented outbreak in Alberta started in the Bow River valley near Banff in 1940. Control measures involving cutting and burning infested trees commenced in 1941 and continued to 1943. The control efforts were successful in reducing beetle populations, and were probably aided by increased moisture conditions and extreme low winter temperatures (Hopping and Mathers 1945). Thirty-thousand trees were treated on a 6075 ha area.

No other known outbreaks occurred in the region until 1976, for a ten-year period, when the beetle caused significant tree mortality in southwestern Alberta and in the Saskatchewan–Alberta portions of the Cypress Hills (Alberta Forest Service 1986). Once initiated, outbreaks usually persist for 8–9 years on the average, during which time the pine component of stands may be drastically depleted (Amman et al. 1977). This outbreak pattern seems to typify the outbreak in southwestern Alberta that began about 1976, expanded rapidly until 1981, and collapsed in 1986, except for a few scattered trees (Table 14). During the course of this outbreak, tree mortality caused by the mountain pine beetle was estimated at 3.48 million trees, and a total volume of 1.15 million m^3 spread over lodgepole pine forests of at least 15 000 ha (Alberta Forest Service 1985).

The eastward and northward spread of the mountain pine beetle prompted an intensive control and salvage program by the Alberta Forest Service and the provincial park and forestry personnel of both Alberta and Saskatchewan governments to prevent further spread and intensification of localized infestations. In Alberta 6.2 million dollars of public funds were spent on the control effort (Alberta Forest Service 1986).

Outbreaks of the mountain pine beetle seldom develop in lodgepole pine stands under 60 years of age, and stands over 80 years present the greatest potential for losses (Safranyik et al. 1974). Hopping and Beall (1948) have shown that few trees with diameters ≤15 cm are attacked, and that there is a rise of 4–5% infestation with each 2.5 cm diameter increase. In a severe outbreak, monitored on 9 plots, in Kootenay National Park 49% of 763 trees with ≤20.3 dbh were killed by the mountain pine beetle, and 88% of 714 trees over 25.4 cm in dbh were killed by the beetle.

Table 14. Summary of mountain pine beetle damage statistics for Alberta from 1977 to 1986 (Table 8; Cerezke and Gates 1982)

Year	Lodgepole pine trees killed	Area infected (ha)	Estimated lodgepole pine volume killed (m^3)
1977	300	–[a]	99
1978	5 500	–	1 815
1979	226 000	–	74 850
1980	835 000	–	275 550
1981	1 250 000	–	412 500
1982	576 000	4 260	190 160
1983	236 000	2 600	79 400
1984	224 700	2 500	75 870
1985	129 600	1 500	42 768
1986	271	–	89
Total	3 483 371	10 860	1 151 831

[a] Data not available.

FOREST TENT CATERPILLAR

The forest tent caterpillar (*Malacosoma disstria* Hbn.) is the most serious defoliator of trembling aspen in the Northwest Region (Ives and Wong 1988). Since the 1980s, widespread infestations in the prairie provinces have been known to occur (Ives 1971). These infestations have recurred at intervals of 6–16 years, and usually last for 4–5 years (Ives and Wong 1988). The caterpillars frequently cause complete defoliation by early summer, with the trees producing new foliage later

the same year. Impacts of the forest tent caterpillar have not been considered serious enough, in the commercial aspen forests of the region, to warrant any large-scale control programs. The greatest concerns have included the maintenance of aesthetics in parks and recreation areas, protection of valued ornamental trees, and the nuisance these invasions of hairy caterpillars and moths cause in public-use areas.

There has been a considerable amount of study on the effects of defoliation by the forest tent caterpillar on trembling aspen. Ives (1971) published an outbreak history of the insect in Alberta. He also studied the effects of 4–6 years of moderate-to-severe defoliation on trees in study plots throughout east-central Alberta. Defoliation levels were determined by ground observations, and radial increments were measured on disks cut from the breast height level of ten trees/plot. Growth was compared to that of four spruce trees growing near the plots.

Ives (1971) concluded that radial growth was gradually reduced during the first 3–4 years of severe defoliation; it then leveled off at less than 10–20% of healthy plots. Trembling aspen, with 4–6 years of defoliation, took about two years to recover after defoliation ceased. Small trees (<12.5 cm dbh) were able to withstand up to six years of moderate-to-severe defoliation without any detectable mortality. Considerable branch mortality occurred in some plots, but this could not be attributed solely to the forest tent caterpillar (Ives 1971).

The history of forest tent caterpillar outbreaks in Manitoba and Saskatchewan were reviewed by Hildahl and Reeks (1960). They also studied the effects of defoliation on tree mortality and growth increment of trembling aspen. Mortality was assessed on two separate sets of plots. The first were 28 mortality plots, which ranged from 0.08 to 0.10 ha in size, and were located in both provinces, and 132 (0.04 ha each in size) inventory plots in Saskatchewan. Stands containing the mortality plots varied in site, density, and degree of defoliation but were mostly even-aged and tended to be mature. Outbreaks in the plot areas rarely lasted more than three years. In the final analysis, it could not be proven that trees on plots subjected to the lightest defoliation history (one year of light defoliation) had significantly less mortality than those subjected to the heaviest defoliation (one year light, two years moderate-to-severe). The inventory plots had variable species compositions and outbreak histories. The authors judged mortality to be high on all plots, but not significantly higher in the defoliated stands. In either case Hildahl and Reeks (1960) could not show that the forest tent caterpillar killed significant numbers of trees, but they did comment on a trend towards higher mortality of suppressed trees.

Growth patterns were studied on sections removed from the stump and mid-crown levels of 4–5 trees/mortality plot (Hildahl and Reeks 1960). One or two years of light-to-moderate defoliation and one year of severe defoliation reduced growth at both levels during the year when severe defoliation occurred, with complete recovery the following year. One year of light defoliation followed by two years of severe defoliation reduced tree growth during the first one or two years following the final defoliation year. Extrapolations from bar charts presented by Hildahl and Reeks (1960) indicated that reductions peaked at about 90% of expected growth. The authors concluded that the forest tent caterpillar caused a striking reduction in radial growth from 1951 to 1954, with loss estimates at 8.4% of total basal area throughout some 610 000 ha of aspen stands in Manitoba and Saskatchewan.

Duncan and Hodson (1958) calculated losses in Minnesota in stands that averaged 1 year of light defoliation and 2 years of heavy defoliation. The volume loss over the 3-year period was 5.4 m^3/ha. For a fully stocked aspen stand on a good site, losses with a similar defoliation history would be approximately 20.15 m^3/ha. The findings of Duncan and Hodson (1958) concurred with the findings of (Ives 1971) as far as negligible mortality by the forest tent caterpillar was concerned. Yet when remeasured six years after defoliation ceased, the same stands showed a relationship between mortality and severity of defoliation for all stands except those with suppressed crown classes (Churchill et al. 1964). This indicates that it may take some time for lethal effects to become apparent and provides what the authors refer to as circumstantial evidence of mortality caused at least indirectly by forest tent caterpillar feeding. The word indirectly is used because hypoxylon canker, *Nectria* spp. fungi, and wood boring insects also increased with intensity of defoliation and contributed to mortality (Churchill et al. 1964).

The studies reviewed would tend to suggest that some mortality follows prolonged periods of forest tent caterpillar defoliation; however, proof of this is not well documented and is confounded by

such factors as competition, disease, etc. (Duncan and Hodson 1958; Hildahl and Reeks 1960; Churchill et al. 1964). What is obvious is that after 3–4 years of severe defoliation radial growth of trembling aspen drops significantly, and that growth may not recover to expected levels for 2–3 years after defoliation ceases (Duncan and Hodson 1958; Hildahl and Reeks 1960; Churchill et al. 1964; Ives 1971). Other studies that support this conclusion are Batzer et al. (1954) and Batzer (1955) (both in Minnesota). The work of Ives (1971) is notable because observations were made in stands defoliated for up to six years in comparison to a maximum of three years for other studies.

SPRUCE BEETLE

The spruce beetle (*Dendroctonus rufipennis* [Kirby]) has caused periodic mortality in stands of white and Engelmann spruce in the Northwest Region. The insect is present in small numbers over wide areas with most outbreaks being associated with favorable breeding opportunities presented by accumulations of logging slash, blowdown, and trees with broken tops (Ives and Wong 1988). The majority of the insect's lifecycle is spent under the bark of host trees, and feeding damage to the cambial area can be extensive given high populations. The life cycle is completed in one to three years, depending on the local temperature regime (Ives and Wong 1988).

Prior to 1971, all known outbreaks in the Northwest Region had occurred in Alberta (Safranyik 1971). Safranyik referred to three major outbreaks. The first occurred in the southwestern portion of the province from 1952 to 1956 and killed an estimated 23% of the mature spruce throughout an area of 486 ha. In Wood Buffalo National Park (early 1960s) up to 5% of the mature spruce were killed over 130 km^2. The final outbreak was again in southwestern Alberta. It began in 1966 following extensive blowdown in mature spruce stands, and peaked in 1968. At the time the work of Safranyik (1971) was published 59 000 m^3 of timber had been killed throughout 1800 ha.

One other major outbreak of the spruce beetle has been reported in the region (Moody and Cerezke 1984, 1985). It occurred throughout a composite area of some 100 000 ha in the Footner Lake and Peace River forests of northern Alberta. The outbreak began around 1977 and continued to the mid-1980s. In one 800–1000 ha stand near Rainbow Lake (where salvage operations were undertaken) about 80 000 m^3 of mortality were caused by the beetle (Moody and Cerezke 1984, 1985).

DISCUSSION

In order to make logical forest management decisions, information regarding the factors that affect the growth and survival of forests must be available. One group of factors that can confound forest management planning are the problems arising from the activities of pests. The preceding summaries have shown that some pest damage progresses insidiously (e.g., decays), while in other cases, there is a sudden and spectacular flare-up of pest populations causing widespread damage for several years before subsiding (e.g., insect outbreaks). In either case the activities of these organisms can bring them into direct competition with man for some forest resources. It has been estimated that the average annual depletion caused by forest pests in Canada during the years 1977–81 was 107.4 million m^3 (Sterner and Davidson 1982); when compared to an annual harvest of 177 million m^3 in 1986 (Forestry Canada 1990), the scope of the losses becomes apparent. The dominant forest management factor in some areas of Canada (e.g., the spruce budworm in New Brunswick) are the activities of pests. This could also have been said to be the case with the mountain pine beetle in the southern portion of Alberta's Bow–Crow Forest in the late 1970s and early 1980s.

It should be apparent that what we consider pests are an integral part of the forest ecosystem. In the case of insects that consume tree tissue, it has been recognized that a certain amount of feeding is normal. Outbreaks sometimes occur in forests under stress or past their prime in terms of biomass production, but in time most forests will return to

a state similar to the preoutbreak condition following insect feeding (Mattson and Addy 1975). The same authors recognized that there are different relationships between insects and their hosts. For example, they suggested that the interaction between the forest tent caterpillar and trembling aspen is largely commensal because few trees (other than suppressed individuals) die during outbreaks. On the other hand the spruce budworm is more parasitic on its host during prolonged and severe periods of defoliation due to the mortality that occurs (Mattson and Addy 1975). These theories may be largely academic to the forest manager faced with a intense outbreak over an extensive area, which is not uncommon in the Northwest Region. In the case of spruce budworm damage, it may be small consultation to know that the forest will gradually recover when faced with an immediate wood shortage. In the case of the forest tent caterpillar, the biomass may remain largely intact, but the quality of the forest for industrial purposes may be reduced due to an associated increase in disease activity.

The forest inventories of the Northwest Region reflect yields from forests that have been largely unprotected from pests. It is realistic to assume that a more aggressive approach to pest management could increase forest yields. A trend towards increased pest management may have already begun with the recent mountain pine beetle control program, and appears to be continuing with attempts to minimize damage by persistent infestations of the spruce budworm in various locations (Emond and Cerezke 1990). The reduction of pest-caused losses does not necessarily require a costly control program. For example, losses to decay can be accomplished by reducing rotation ages (Waters and Cowling 1976). Ensuring that susceptible regeneration is not established adjacent to dwarf mistletoe centers is another example. This can be done before the area is harvested by considering this factor during the layout of cut blocks.

Reviews of scientific literature can be used as a tool to highlight gaps in existing knowledge bases. This report has helped assess the volume of data available and has helped identify areas where research is needed.

This is particularly true of root rots and hypoxylon canker. In both of these cases, some basic surveys could increase the information base considerably. Whitney et al. (1983) referred to disease loss data (in Canada in general) as being fragmentary and imprecise. He expressed a need for trained observers to apply survey techniques and provide precise estimates that include projections of future losses. More importantly, these comments apply to the information available on the impacts of all inimical agents affecting forest productivity in the Northwest Region.

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REFERENCES

Alberta Forest Service. 1985. Alberta phase 3 inventory, an overview. Alberta For., Lands Wildl., Edmonton, Alberta. ENR Rep. I/86.

Alberta Forest Service. 1986. Mountain pine beetle control program, 1980–86: a success story. Alberta For. Lands Wildl., Edmonton, Alberta. Publ. I/143.

Amman, G.D.; McGregor, M.D.; Cahill, D.B.; Klein, W.H. 1977. Guidelines for reducing losses of lodgepole pine to the mountain pine beetle in unmanaged stands in the Rocky Mountains. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT - 36.

Anderson, G.W.; Martin, M.P. 1981. Factors related to the incidence of Hypoxylon cankers in aspen, and survival of cankered trees. For. Sci. 27:461–476.

Bailey, G.R.; Dobie, J. 1977. Alberta poplars—tree and log quality. Can. Dep. Fish. Environ., West. For. Prod. Lab., Vancouver, British Columbia. Inf. Rep. VP-X-155.

Baranyay, J.A. 1963. Forest disease conditions, Province of Alberta. *In* Annual report of the forest insect and disease survey. Can. Dep. For., Ottawa, Ontario.

Baranyay, J.A. 1964. Forest disease conditions. Pages 102–108 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A. 1965. Forest disease conditions. Pages 102–110 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A. 1967. Notes on *Hypoxylon* canker of aspen in Alberta. For. Chron. 43:372–380.

Baranyay, J.A. 1970. Lodgepole pine dwarf mistletoe in Alberta. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario. Publ. 1286.

Baranyay, J.A.; Bourchier, R.J. 1961. Province of Alberta forest disease survey. Pages 88–92 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A.; Bourchier, R.J. 1963. Forest disease conditions. Pages 99–105 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A.; Bourchier, R.J.; Stevenson, G.R. 1962. Province of Alberta forest disease survey. Pages 102–106 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Baranyay, J.A.; Safranyik, L. 1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario. Publ. 1285.

Baranyay, J.A.; Stevenson, G.R. 1964. Mortality caused by armillaria root rot, peridermium rusts and other destructive agents in lodgepole pine regeneration. For. Chron. 40:350–361.

Baranyay, J.A.; Stevenson, R.E. 1966. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 81–92 *in* Annual report of the forest insect and disease survey 1965. Dep. For., Ottawa, Ontario.

Baranyay, J.A.; Szabo, T.; Hunt, K. 1973. Effect of *Atropellis* canker on growth and utilization of lodgepole pine. Can. For. Serv., Pac. For. Cent., Victoria, British Columbia. Inf. Rep. BC-X-86.

Barker, R. 1949. Provinces of Manitoba and Saskatchewan forested area. Pages 73–89 *in* Annual report of the forest insect survey, forest insect investigations, 1948. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Barker, R.B.; Wong, H.R. 1948. Prairie provinces forested area. Pages 64–79 *in* Annual report of the forest insect survey, forest insect investigations, 1947. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Basham, J.T. 1966. Heart rot of jack pine in Ontario. I. The occurrence of basidiomycetes and microfungi in defective and normal heartwood of living trees. Can. J. Bot. 44:275–295.

Basham, J.T. 1967. Heart rot of jack pine in Ontario. III. Decay relationships and their effects on management. For. Chron. 43:222–238.

Basham, J.T. 1984. Degradation and loss of wood fibre in spruce budworm-killed timber, and effects on utilization. For. Chron. 60:10–14.

Basham, J.T.; Morawski, Z.I.R. 1964. Cull studies, the defects and associated basidiomycete fungi in the heartwood of living trees in the forest of Ontario. Can. Dep. For., Ottawa, Ontario. Publ. 1972.

Batzer, H.O. 1955. Effects of defoliation by the forest tent caterpillar. Proc. North Cent. Branch Entmol. Soc. Am. 10:27–28.

Batzer, H.O. 1973. Net effect of spruce budworm defoliation on mortality and growth of balsam fir. J. For. 71:34–37.

Batzer, H.O.; Hodson, A.C.; Schneider, A.E. 1954. Preliminary results of an inquiry into effects of defoliation of aspen trees by the forest tent caterpillar. Univ. Minn. Agric. Exp. Stn. J. Ser. Pap. 3169.

Bourchier, R.J. 1953. Forest disease survey, Alberta and Rocky Mountain national parks. Pages 121–126 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1954a. Prairie provinces, Alberta and Rocky Mountain national parks forest disease survey. Pages 128–135 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1954b. Province of Alberta forest disease survey. Pages 108–114 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1956. Province of Alberta forest disease survey. Pages 89–91 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Bourchier, R.J. 1957. Province of Alberta forest disease survey. Pages 77–78 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brandt, N.R.; McDowall, L.L. 1968. Jack-pine budworm in Manitoba and Saskatchewan, 1938–1967. Can. Dep. Rural Dev., Winnipeg, Manitoba. Inf. Rep. MS-X-8.

Brown, A.W.A. 1940. Annual report of the forest insect survey 1939. Pages 5–30 *in* Annual report of the forest insect survey 1939. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, A.W.A. 1941. Annual report of the forest insect survey. Pages 5–27 *in* Annual report of the forest insect survey, forest insect investigations, 1940. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, A.W.A. 1942. Annual report of the forest insect survey 1941. Pages 3–23 *in* Annual report of the forest insect survey, forest insect investigations, 1941. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, A.W.A. 1943. Annual report of the forest insect survey, 1942. *In* Annual report of the forest insect survey, forest insect investigations, 1942. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, A.W.A. 1959a. The forest insect survey, 1937. Report of the Ottawa Section. Pages 13–20 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, A.W.A. 1959b. The forest insect survey 1938. Summary report of the Ottawa Section. Pages 36–48 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E. 1963. Damage to spruce by the spruce budworm. Can. Dep. For., Bi-Mon. Prog. Rep., Ottawa, Ontario. 19(2):2–3.

Brown, C.E.; Cumming, M.E.P. 1950. Prairie provinces agricultural area. Pages 85–96 *in* Annual report of the forest insect survey, forest insect investigations, 1949. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1951. Prairie provinces agricultural area. Pages 83–95 *in* Annual report of the forest insect survey 1950. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1952. Prairie provinces agricultural area. Pages 83–93 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1953. Forest insect survey, agricultural area. Pages 100–111 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P. 1954. Prairie provinces agricultural area forest insect survey. Pages 112–120 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; McGuffin, W.C. 1954. Province of Alberta forest insect survey. Pages 102–107 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; Robins, J.K. 1956. Province of Alberta forest insect survey. Pages 83–88 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; Robins, J.K. 1957. Province of Alberta forest insect survey. Pages 72–76 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Cumming, M.E.P.; Robins, J.K. 1958. Province of Alberta forest insect survey. Pages 65–69 *in* Annual report of the forest insect and disease survey 1957. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Hopkins, M.C.; Robins, J.K. 1959. Province of Alberta forest insect survey. Pages 74–80 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Hopkins, M.C.; Robins, J.K. 1960. Province of Alberta forest insect survey. Pages 81–87 *in* Annual reportof the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Brown, C.E.; Robins, J.K.; Stevenson, R.E. 1961. Province of Alberta forest insect survey. Pages 81–87 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Robins, J.K.; Stevenson, R.E. 1962. Province of Alberta forest insect survey. Pages 92–101 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Stevenson, R.E. 1963. Forest insect conditions. Pages 92–98 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Stevenson, R.E. 1964. Province of Alberta, forest insect and disease survey. Forest insect conditions. Pages 96–101 *in* Annual report of the forest insect and disease survey, 1963. Can. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Brown, C.E.; Stevenson, R.E. 1965. Province of Alberta, forest insect and disease survey. Forest insect conditions. Pages 97–102 *in* Annual report of the forest insect and disease survey, 1964. Can. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Cerezke, H.F. 1978a. Spruce budworm—how important is it here in the West? Environ. Can., Can. For. Serv., North. For.Res. Cent., Edmonton, Alberta. For. Rep. (Spring 1978): 4–5.

Cerezke, H.F. 1978b. Jack pine budworm. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. For. Rep. (Spring 1978): 6.

Cerezke, H.F. 1986. Impact studies of the jack pine budworm, *Choristoneura pinus pinus*, in Nisbet Provincial Forest, Saskatchewan. Pages 25–38 *in* Jack pine budworm information exchange. Manit. Nat. Resour., Winnipeg, Manitoba.

Churchill, G.B.; Johns, H.H.; Duncan, D.P.; Hodson, A.C. 1964. Long-term effects of defoliation of aspen by the forest tent caterpillar. Ecology 45:630–633.

Copony, J.A.; Barnes, B.V. 1974. Clonal variation in the incidence of hypoxylon canker on trembling aspen. Can. J. Bot. 52: 1475–1481.

DeBoo, R.F.; Hildahl, V. 1968. Jack pine budworm in central Canada. Can. Dep. For. Rural Dev., Winnipeg, Manitoba. Liaison Serv. Note MS-L-4.

Department of Agriculture. 1959. The insect survey in 1936. *In* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario.

Department of Forestry. 1963a. Alberta forest insect and disease survey. Pages 91–92 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1963b. Manitoba and Saskatchewan forest insect and disease survey. Page 77 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1964a. Manitoba and Saskatchewan forest insect and disease survey. Pages 75–76 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1964b. Province of Alberta forest insect and disease survey. Pages 95–96 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1965a. Manitoba and Saskatchewan forest insect and disease survey. Pages 78–79 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Department of Forestry. 1965b. Province of Alberta forest insect and disease survey. Pages 96–97 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Duncan, D.P.; Hodson, A.C. 1958. Influence of forest tent caterpillar upon the aspen forests of Minnesota. For. Sci. 4:71–93.

Edmonton Environment Development Authority. 1989. Edmonton report on economic development. Edmonton Econ. Dev. Auth., Edmonton, Alberta. 25(3).

Elliott, K.R.; Hildahl, V. 1962. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 77–89 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1963. Forest insect conditions. Pages 78–85 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1964. Forest insect conditions. Pages 76–85 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Hildahl, V. 1965. Forest insect conditions. Pages 79–89 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Elliott, K.R.; Laut, J.G. 1966. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 66–80 *in* Annual report of the forest insect and disease survey 1965. Dep. For., Ottawa, Ontario.

Elliott, K.R.; Laut, J.G.; Brandt, N.R. 1967. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 75–94 *in* Annual report of the forest insect and disease survey 1966. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Emond, F.J.; Cerezke, H.F. 1989. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1988 and predictions for 1989. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-303.

Emond, F.J.; Cerezke, H.F. 1990. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1989 and predictions for 1990. For. Can., Northwest Reg., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-313.

Etheridge, D.E. 1958. Decay losses in subalpine spruce on the Rocky Mountain Forest Reserve in Alberta. For. Chron. 34:116–131.

Forestry Canada. 1990. Forestry facts. For. Can., Ottawa, Ontario.

Gross, H.L. 1985. The impact of insects and diseases on the forests of Ontario. Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ontario. Inf. Rep. O-X-366.

Hawksworth, F.G. 1958. Survey of lodgepole pine dwarf mistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. U.S. Dep. Agric., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colorado. Stn. Pap. 35.

Hawksworth, F.G.; Johnson, D.W. 1989. Biology and management of dwarf mistletoe in lodgepole pine in the Rocky Mountains. U.S. Dep. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colorado. Gen. Tech. Rep. RM-169.

Hewitt, C.G. 1911. The spruce budworm and larch sawfly. Can. For. Conv. Quebec City, Quebec. Misc. Publ.

Hildahl, V.; Reeks, W.A. 1960. Outbreaks of the forest tent caterpillar, *Malacosoma disstria* Hbn., and their effects on stands of trembling aspen in Manitoba and Saskatchewan. Can. Entomol. 92:199–209.

Hildahl, V.H.; DeBoo, R.F. 1973. Aerial applications of chemical insecticides against the spruce budworm in Manitoba, 1973. Manit. Entomol. 7:6–14.

Hinds, T.E. 1985. Diseases. Pages 87–106 *in* N.V. DeByle and R.P. Winokur, eds. Aspen: ecology and management in the western United States. U.S. Dep. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colorado. Gen. Tech. Rep. RM-119.

Hinds, T.E.; Harrell, M.O. 1986. Hypoxylon canker of aspen. Pages 58–59 *in* J.W. Riffle and G.W. Peterson, tech. coords. Diseases of trees in the Great Plains. U.S. Dep. Agric., For. Serv., Rocky Mtn. For. Range Exp. Stn., Fort Collins, Colorado. Gen. Tech. Rep. RM-129.

Hiratsuka, Y. 1987. Forest tree diseases of the prairie provinces. Can. For. Serv., North. For. Cent., Edmonton, Alberta Inf. Rep. NOR-X-286.

Hiratsuka, Y.; Cerezke, H.F.; Petty, J. 1982. Prairies region. Important forest insects. Important forest diseases. Pages 59–69 *in* Annual reports of the forest insect and disease survey 1978 and 1979. Annual report 1979. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Hiratsuka, Y.; Cerezke, H.F.; Petty, J.; Still, G.N. 1981. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1980 and predictions for 1981. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-231.

Hiratsuka, Y.; Gibbard, D.A.; Bakowsky, O.; Maier, G.B. 1990. Classification of aspen decay and stain in Alberta. For. Can., Northwest Reg., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-314.

Hiratsuka, Y.; Loman, A.A. 1984. Decay of aspen and balsam poplar. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-262.

Hiratsuka, Y.; Petty, J. 1981. Prairies region. Important forest insects. Important forest diseases. Pages 71–79 *in* Annual report of the forest insect and disease survey, 1977. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Hiratsuka, Y.; Petty, J. 1982. Prairies region. Important forest insects. Important forest diseases. Pages 55–61 *in* Annual report of the forest insect and disease survey 1978 and 1979.Annual report 1978. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Hopkins, J.C. 1963. Atropellis canker of lodgepole pine: etiology, symptoms, and canker development rates. Can. J. Bot. 41:1535–1545.

Hopkins, J.C. 1985. *Atropellis* canker. Can. For. Serv. ,Pac. For. Res. Cent., Victoria, British Columbia. For. Pest Leafl. 25 (rev.).

Hopping, G.R.; Beall, G. 1948. The relation of diameter of lodgepole pine to incidence of attack by the bark beetle (*Dendroctonus monticulae* Hopkins). For. Chron. 24:141–145.

Hopping, G.R.; Mathers, W.G. 1945. Observations on outbreak and control of the mountain pine beetle in the lodgepole pine stands of western Canada. For. Chron. 21:98–108.

Hopping, R. 1959. The forest insect survey, 1937. Summary report of the 1937 forest insect survey in British Columbia. Pages 26–34 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Dep. Agric., Ottawa, Ontario.

Hopping, R.; Leech, H.B. 1959. The forest insect survey 1938. Summary report of British Columbia Section. Pages 53–55 *in* Annual reports of the forest insect survey 1936–1937–1938. For. Biol. Div., Res. Branch, Sci. Serv., Dep. Agric., Ottawa, Ontario.

Howse, G.M. 1984. Insects pests of jack pine: biology, damage and control. Pages 131–138 *in* Proc. Jack Pine Symp., October 18–20, 1983, Timmins, Ontario. Environ. Can., Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ontario. COJFRC Symp. Proc. O-P-12.

Howse, G.M.; Harnden, A.A.; Meating, J.H.; Carrow, J.R. 1981. The 1980 spruce budworm situation in Ontario. Can. Dep. Environ., Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ontario. Inf. Rep. O-X-336.

Ives, W.G.H. 1969. Forest insects in Saskatchewan. Pages 97–102 *in* J.R. Richards and J.K. Fung, eds. Atlas of Saskatchewan. Univ. Saskatchewan, Saskatoon, Saskatchewan.

Ives, W.G.H.; Blauel, R.A.; Robins, J.K. 1971. Prairies region. Important forest insects. Important forest diseases. Pages 67–76 *in* Annual report of the forest insect and disease survey 1970. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Blauel, R.A.; Robins, J.K. 1972. Prairies region. Important forest insects. Important forest diseases. Pages 73–80 *in* Annual report of the forest insect and disease survey, 1971. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Brandt, N.R.; Lawrence, J.J. 1969. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 79–97 *in* Annual report of the forest insect and disease survey 1968. Can. Dep. Fish. For., For. Branch, Ottawa, Ontario.

Ives, W.G.H.; Brandt, N.R.; Laut, J.G. 1970. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 72–83 *in* Annual report of the forest insect and disease survey 1969. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Brandt, N.R.; Sutton, B.C. 1968. Manitoba–Saskatchewan region. Important forest insects. Important forest diseases. Pages 76–96 *in* Annual report of the forest insect and disease survey 1967. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Ives, W.G.H.; Lawrence, J.J.; Petty, J., Robins, J.K. 1975. Prairies region. Important forest insects. Important forest diseases. Pages 75–81 *in* Annual report of the forest insect and disease survey, 1974. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Lawrence, J.J.; Robins, J.K. 1973. Prairies region. Important forest insects. Important forest diseases. Pages 74–81 *in* Annual report of the forest insect and disease survey, 1972. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Lawrence, J.J.; Robins, J.K. 1974. Prairies region. Important forest insects. Important forest diseases. Pages 70–77 *in* Annual report of the forest insect and disease survey, 1973. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Petty, J. 1976. Prairie region. Important forest insects. Important forest diseases. Pages 69–74 *in* Annual report of the forest insect and disease survey, 1975. Fish. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Ives, W.G.H.; Wong, H.R. 1988. Tree and shrub insects of the prairie provinces. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-292.

Jacquith, P.H.; Duncan, D.P.; Kulman, H.M.; Hodson, A.C. 1958. Preliminary study of growth losses in Minnesota jack pine following defoliation by the budworm (*Choristoneura pinus*). Minn. For. Notes 74:1–2.

Kirby, C.L.; Bailey, W.S.; Gilmour, J.G. 1957. Growth and yield of aspen in Saskatchewan. Sask. Dep. Nat. Resour., For. Branch. Tech. Bull. No. 3.

Kondo, E.S.; Moody, B.H.; compilers. 1987. Forest insect and disease conditions in Canada 1986. Forest insect and disease survey. Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Taylor, R.G.; compilers. 1984. Forest insect and disease conditions in Canada 1983. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Taylor, R.G.; compilers. 1985. Forest insect and disease conditions in Canada 1984. Forest insect and disease survey. Can. For. Serv., Ottawa, Ontario.

Kondo, E.S.; Taylor, R.G.; compilers. 1986. Forest insect and disease conditions in Canada 1985. Forest insect and disease survey. Can. For. Serv., Ottawa, Ontario.

Kulman, H.M. 1971. Effects of insect defoliation on growth and mortality of trees. Annu. Rev. Entomol. 16:289–324.

Kulman, H.M.; Hodson, A.C. 1961. The jack pine budworm as a pest of other conifers with special reference to red pine. J. Econ. Entomol. 54:1221–1224.

Kulman, H.M.; Hodson, A.C.; Duncan, D.P. 1963. Distribution and effects of jack pine budworm defoliation. For. Sci. 9:146–157.

Laut, J.G.; Hildahl, V. 1965. Forest disease conditions. Pages 90–95 *in* Annual report of the forest insect and disease survey 1964. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Leech, H.B. 1944. Summary report of forest survey, British Columbia and western Alberta. Pages 62–68 *in* Annual report of the forest insect survey, forest insect investigations, 1943. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1945. Summary report of the forest insect survey, British Columbia and Rocky Mountain national parks. Pages 62–70 *in* Annual report of the forest insect survey, forest insect investigations, 1944. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1946. British Columbia and Rocky Mountain national parks. Pages 61–67 *in* Annual report of the forest insect survey, forest insect investigations, 1945. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Leech, H.B. 1947. British Columbia and Rocky Mountain national parks. Pages 77–86 *in* Annual report of the forest insect survey, forest insect investigations, 1946. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.Alberta Forest Service. 1985. Alberta phase 3 inventory, an overview. Alberta For., Lands Wildl., Edmonton, Alberta. ENR Rep. I/86.

Lejeune, R.R. 1946. Prairie provinces forested area. Pages 43–52 *in* Annual report of the forest insect survey, forest insect investigations, 1945. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Loman, A.A. 1958. Province of Alberta forest disease survey. Pages 70–71 *in* Annual report of the forest insect and disease survey 1957. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Loman, A.A.; Bourchier, R.J. 1959. Province of Alberta forest disease survey. Pages 81–83 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Loman, A.A.; Paul, G.D. 1963. Decay of lodgepole pine in two foothills sections of the boreal forest in Alberta. For. Chron. 39:422–435.

MacLean, D.A. 1985. Effects of spruce budworm outbreaks on forest growth and yield. Pages 148–175 *in* C.J. Sanders, R.W. Stark, E.J. Mullins, and J. Murphy, eds. Recent advances in spruce budworm research. Proc. CANUSA Spruce Budworm Res. Symp., September 16–20, 1984, Bangor, Maine. Can. For. Serv., Ottawa, Ontario.

MacLean, D.A. 1990. Impact of forest pests and fire on stand growth and timber yield: implications for forest management planning. Can. J. For. Res. 20:391–404.

MacKay, M.R. 1948. British Columbia and Rocky Mountain national parks. Pages 91–102 *in* Annual report of the forest insect survey, forest insect investigations, 1947. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Mallett, K.I. 1990. Host range and geographic distribution of *Armillaria* root rot pathogens in the Canadian prairie provinces. Can. J. For. Res. 20:1859–1863.

Manion, P.D. 1981. Tree disease concepts. Prentice-Hall Inc., Englewood Cliffs, N.J.

Manion, P.D.; Griffin, D.H. 1986. Sixty-five years of research on hypoxylon canker of aspen. Plant Dis. 70:803–808.

Mattson, J.M.; Addy, N.D. 1975. Phytophagous insects as regulators of forest primary production. Science 190:515–522.

McGuffin, W.C. 1949. Alberta and Rocky Mountain national parks. Pages 102–109 *in* Annual report of the forest insect survey, forest insect investigations, 1948. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1950. Alberta and Rocky Mountain national parks. Pages 97–104 *in* Annual report of the forest insect survey, forest insect investigations, 1949. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1953. Forest insect survey, Alberta, Rocky Mountain national parks, and Northwest Territories. Pages 112—120 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C. 1954. Prairie provinces, Alberta and Rocky Mountain national parks forest insect survey. Pages 121–127 *in* Annual report of the forest insect and disease survey1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C.; Barker, R.B. 1947. Prairie provinces forested area. Pages 54–65 *in* Annual report of the forest insect survey, forest insect investigations, 1946. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C.; Reid, R.W. 1951. Alberta and Rocky Mountain national parks. Pages 96–105 *in* Annual report of the forest insect survey 1950. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

McGuffin, W.C.; Reid, R.W. 1952. Alberta and Rocky Mountain national parks. Pages 94–103 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Moody, B.H. 1986. The jack pine budworm, history of outbreaks, damage, and FIDS sampling and prediction systems in the prairie provinces. Pages 15–22 *in* Jack pine budworm information exchange. Manit. Nat. Resour., Winnipeg, Manitoba.

Moody, B.H.; compiler. 1988. Forest insect and disease conditions in Canada 1987. Forest insect and disease survey. For. Can., Petawawa Nat. For. Inst., Chalk River, Ontario.

Moody, B.H.; compiler. 1990. Forest insect and disease conditions in Canada 1988. Forest insect and disease survey. For. Can., Petawawa Nat. For. Inst., Chalk River, Ontario.

Moody, B.H.; Cerezke, H.F. 1984. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1983 and predictions for 1984. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-261.

Moody, B.H.; Cerezke, H.F. 1985. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1984 and predictions for 1985. Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-269.

Moody, B.H.; Cerezke, H.F. 1986. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1985 and predictions for 1986. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-276.

Morawski, Z.J.R.; Basham, J.T.; Turner, K.B. 1958. Cull studies, a survey of a pathological condition in the forests of Ontario. Ont. Dep. Lands For., Div. Timber Manage. Rep. 25.

Nevill, R.J.; Merler, H.; Borden, J.H. 1989. Reduced volume, grade and value of lodgepole pine lumber caused by *Atropellis* canker and stalactiform blister rust. For. Chron. 65: 36–41.

Overpeck, J.T.; Rind, D.; Goldberg, R. 1990. Climate-induced changes in forest disturbance and vegetation. Nature 343:51–53.

Pedology Consultants. 1982. Evaluation of the hardwood resources of the O'Chiese Block in the Rocky–Clearwater Forest. Alberta Dep. Environ., For. Serv., Edmonton, Alberta.

Peterson, L. 1944. Summary report of the forest insect survey, agricultural area, prairie provinces. Pages 56–61 *in* Annual report of the forest insect survey, forest insect investigations, 1943. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L.O.T. 1945. Summary report of the forest insect survey, agricultural area, prairie provinces. Pages 52–61 *in* Annual report of the forest insect survey, forest insect investigations, 1944. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L.O.T. 1946. Prairie provinces agricultural area. Pages 53–60 *in* Annual report of the forest insect survey, forest insect investigations, 1945. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Peterson, L.O.T.; Sandercock, E.M. 1947. Prairie provinces agricultural area. Pages 66–76 *in* Annual report of the forest insect survey, forest insect investigations, 1946. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Petty, J. 1979. Prairie region. Important forest insects. Important forest diseases. Pages 71–75 *in* Annual report of the forest insect and disease survey, 1976. Dep. Environ., Can. For. Serv., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1954a. Prairie provinces, provinces of Manitoba and Saskatchewan forested area forest insect survey. Pages 91–103 *in* Annual report of the forest insect

and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1954b. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 82–96 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1956. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 70–81 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1957. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 60–70 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. of Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1958. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 53–64 *in* Annual report of the forest insect and disease survey 1957. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1959. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 62–71 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1960. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 68–78 *in* Annual report of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Prentice, R.M.; Hildahl, V. 1961. Provinces of Manitoba and Saskatchewan forest insect survey. Pages 68–77 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Richmond, H.A.; McGuffin, W.C. 1945. Summary report of the forest insect survey, central Canada. Pages 40–51 *in* Annual report of the forest insect survey, forest insect investigations, 1944. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Richmond, H.A.; Smith, D.N. 1944. Summary report of the forest insect survey, forest area prairie provinces and far western Ontario. Pages 46–55 *in* Annual report of the forest insect survey, forest insect investigations, 1943. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Riley, C.G. 1955. Diseases of Saskatchewan forests. Pages 99–115 *in* Saskatchewan's forests. Sask. Dep. Nat. Resour., Regina, Saskatchewan. Misc. Publ.

Riley, C.G.; Denyer, W.B.; Whitney, R.D. 1952. Prairie provinces. Pages 140–146 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Riley, C.G.; Hildahl, V. 1963. Forest disease conditions. Pages 86–90 *in* Annual report of the forest insect and disease survey 1962. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Riley, C.G.; Hildahl, V. 1964. Forest disease conditions. Pages 85–94 *in* Annual report of the forest insect and disease survey 1963. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Riley, C.G.; Zalasky, H. 1962. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 92–101 *in* Annual report of the forest insect and disease survey 1961. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Ross, W.D. 1976. Fungi associated with rust diseases of aspen in Wyoming. Can. J. Bot. 54:734–744.

Rowe, J.S. 1972. Forest regions of Canada. Environ. Can., Can. For. Serv., Ottawa, Ontario. Publ. 1300.

Safranyik, L. 1971. Spruce beetle. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. For. Rep. 1(4).

Safranyik, L.; Shrimpton, D.M.; Whitney, H.S. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Environ. Can., Can. For. Serv., Pac. For. Res. Cent., Victoria, British Columbia. For. Tech. Rep. 1.

Sandercock, E.M.; Cumming, M.E.P. 1949. Prairie provinces agricultural area. Pages 90–101 *in* Annual report of the forest insect survey, forest insect investigations, 1948. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Sandercock, E.M.; Peterson, L.O.T. 1948. Prairie provinces agricultural area. Pages 80–90 *in* Annual report of the forest insect survey, forest insect investigations, 1947. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Smerlis, E. 1961. Pathological condition of immature balsam fir stands of Hylocomium–Oxales type in the Laurentide Park, Quebec. For. Chron. 37:109–115.

Stanek, W.; Hopkins, J.C.; Simmons, C.S. 1986. Effect of spacing in lodgepole pine stands on incidence of atropellis canker. For. Chron. 62:91–95.

Sterner, T.E.; Davidson, A.G., compilers. 1981. Forest insect and disease conditions in Canada 1980. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Sterner, T.E.; Davidson, A.G., compilers. 1982. Forest insect and disease conditions in Canada, 1981. For. Insect Dis. Surv., Environ. Can., Can. For. Serv., Ottawa, Ontario.

Sterner, T.E.; Davidson, A.G., compilers. 1983. Forest insect and disease conditions in Canada 1982. Forest insect and disease survey. Environ. Can., Can. For. Serv., Ottawa, Ontario.

Stevenson, R.E. 1970. The spruce budworm in northern Alberta: with emphasis on the Wabasca outbreak. Can. Dep. Fish. For., Can. For. Serv., For. Res. Lab., Calgary, Alberta. Intern. Rep. A-28.

Thomas, G.P. 1968. Decay as a limiting factor on poplar utilization. Pages 145–148 *in* J.S. Maini and J.H. Cayford, eds. Growth and utilization of poplars in Canada. Can.

Dep. For. Rural Dev., For. Branch Dep., Ottawa, Ontario. Publ. 1205.

Thomas, G.P.; Bourchier, R.J.; Loman, A.A. 1960. Province of Alberta forest disease survey. Pages 88–92 *in* Annual report of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Thomas, G.P.; Etheridge, D.E.; Paul, G. 1960. Fungi and decay in aspen and balsam poplar in the boreal forest region, Alberta. Can. J. Bot. 38:459–466.

Thomas, R.W. 1953. Forest disease survey, provinces of Manitoba and Saskatchewan forest area. Pages 92–99 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Thomas, R.W. 1954. Prairie provinces, provinces of Manitoba and Saskatchewan forest disease survey. Pages 104–111 *in* Annual report of the forest insect and disease survey 1953. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Tripp, H.A.; Blauel, R.A. 1969. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 98–110 *in* Annual report of the forest insect and disease survey 1968. Can. Dep. Fish. For., For. Branch, Ottawa, Ontario.

Tripp, H.A.; Robins, J.K. 1968. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 97–107 *in* Annual report of the forest insect and disease survey 1967. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Tripp, H.A.; Robins, J.K.; Blauel, R.A. 1970. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 84–96 *in* Annual report of the forest insect and disease survey 1969. Can. Dep. Fish. For., Can. For. Serv., Ottawa, Ontario.

Tripp, H.A.; Stevenson, R.E.; Baranyay, J.A. 1967. Alberta–Northwest Territories–Yukon region. Important forest insects. Important forest diseases. Pages 95–107 *in* Annual report of the forest insect and disease survey 1966. Can. Dep. For. Rural Dev., For. Branch, Ottawa, Ontario.

Volney, W.J.A. 1988. Analysis of historic jack pine budworm outbreaks in the prairie provinces of Canada. Can. J. For. Res. 18:1152–1158.

Wall, R.E. 1971. Variation in decay in aspen stands as affected by their clonal growth pattern. Can. J. For. Res. 1:141–148.

Waters, W.E.; Cowling, E.B. 1976. Integrated forest pest management: a silvicultural necessity. Pages 149–177 *in* J.L. Apple and R.F. Smith, eds. Integrated pest management. Plenum Press, N.Y.

Whitney, R.D. 1952. Root diseases of balsam fir. Can. Dep. Agric., For. Biol. Div. Bi-Mon. Prog. Rep. 8(5):2.

Whitney, R.D. 1961. Root wounds and associated root rots of white spruce. For. Chron. 37: 401–411.

Whitney, R.D. 1973. Root rot losses in upland spruce at Candle Lake, Saskatchewan. For. Chron. 49:176–179.

Whitney, R.D. 1978. Root rot of spruce and balsam fir in northwestern Ontario. II. Causal fungi and site relationships. Environ. Can., Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ontario. Rep. O-X-284.

Whitney, R.D.; Hunt, R.S.; Munro, J.A. 1983. Impact and control of forest diseases in Canada. For. Chron. 59:223–228.

Witter, J.; Ostaff, D.; Montgomery, B. 1984. Damage assessment. Pages 37–64 *in* D.M. Schmitt, D.G. Grimble, and J.L. Searcy, tech. coords. Spruce budworms handbook. Managing the spruce budworm in eastern North America. U.S. Dep. Agric., For. Serv., Washington, D.C. Agric. Handb. 620.

Wong, H.R.; Hildahl, V.; Prentice, R.M. 1952. Provinces of Manitoba and Saskatchewan forested area. Pages 66–82 *in* Annual report of the forest insect and disease survey 1951. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wong, H.R.; Prentice, R.M.; Hildahl, V. 1953. Prairie provinces forest insect survey, provinces of Manitoba and Saskatchewan forest area. Pages 79–91 *in* Annual report of the forest insect and disease survey 1952. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wong, H.R.; Smith, J.D.; Hildahl, V. 1950. Provinces of Manitoba and Saskatchewan forested area. Pages 70–84 *in* Annual report of the forest insect survey, forest insect investigations, 1949. Div. Entomol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wong, H.R.; Turnock, W.J.; Hildahl, V. 1951. Provinces of Manitoba and Saskatchewan forested area. Pages 69–82 *in* Annual report of the forest insect survey 1950. Div. For. Biol., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Wotton, D.L.; Jones, D.C.; McEachern, D.B. 1978. An assessment of jack pine budworm control in the Bélair Provincial Forest, Manitoba. Manit. Dep. Mines Nat. Resour. Environ., Environ. Res. Dev. Branch. Rep. 78-1.

Zalasky, H. 1954. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 97–101 *in* Annual report of the forest insect and disease survey 1954. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1956. Provinces of Manitoba and Saskatchewan forest disease survey. Page 82 *in* Annual report of the forest insect and disease survey 1955. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1959. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 72–73 *in* Annual report of the forest insect and disease survey 1958. For. Biol. Div., Sci. Serv., Can. Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1960. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 79–80 *in* Annual report of the forest insect and disease survey 1959. For. Biol. Div., Can. Dep. Agric., Ottawa, Ontario.

Zalasky, H. 1961. Provinces of Manitoba and Saskatchewan forest disease survey. Pages 78–80 *in* Annual report of the forest insect and disease survey 1960. Dep. For., For. Entomol. Pathol. Branch, Ottawa, Ontario.

Zalasky, H.; Riley, C.G. 1957. Provinces of Manitoba and Saskatchewan forest disease survey. Page 71 *in* Annual report of the forest insect and disease survey 1956. For. Biol. Div., Sci. Serv., Dep. Agric., Ottawa, Ontario.

Zoltai, S.C.; Singh, T.; Apps, M.J. 1991. Aspen in a changing climate. Pages 143–152 *in* S. Navratil and P.B. Chapman, eds. Aspen management for the 21st century. Proceedings of a symposium held November 20–21, 1990, Edmonton, Alberta. For. Can., Northwest Reg., North. For. Cent. and Poplar Counc. Can., Edmonton, Alberta.

Unpublished reports:

Amirault, P.A.; Pope, B. 1989. Pest distribution and impact in young lodgepole pine stands in west-central Alberta. For. Can., North. For. Cent., Edmonton, Alberta. Canada–Alberta For. Resour. Dev. Agreement.

Basham, J.T. 1987. Assessment and prediction of stem decay in aspen stands. Pages 110–117 *In* Proc. Aspen Quality Workshop, February 12, 1987, Edmonton, Alberta. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Canada–Alberta For. Resour. Dev. Agreement.

Black, R.L.; Kristapovich, P.J. 1954. Decay of trembling aspen in Manitoba and eastern Saskatchewan. Can. Dep. Agric., For. Biol. Div., Saskatoon, Saskatchewan. Mimeograph.

Cerezke, H.F. 1976. Spruce budworm impact studies in spruce forests of northern Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Unpubl. File Rep.

Cerezke, H.F.; Gates, H. S. 1982. Surveys and impact estimations of mountain pine beetle damage in the Bow–Crow Forest, Alberta, during 1982. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Unpubl. File Rep. NOR-143-033.

Denyer, W.B.G.; Riley, C.G. 1954. Interim report on decay of white spruce in the prairie provinces. Can. Dep. Agric., Res. Branch, For. Biol. Div., Saskatoon, Saskatchewan. Mimeograph.

Ives, W.G.H. 1971. The forest tent caterpillar in Alberta. Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Unpubl. Intern. Rep. NOR-4.

Maier, G.B.; Darrah, D. 1989. Decay levels in mature aspen stands Whitecourt, Alberta. For. Can., North. For. Cent., Edmonton, Alberta. Canada–Alberta. For. Resour. Dev. Agreement.

Paul, G.; Etheridge, D.E. 1958. Decay of aspen (*Populus tremuloides* Michx.) and balsam poplar (*P. balsamifera* L.) in the Lesser Slave Lake region in Alberta. Alberta Dep. Land. For., For. Surv. Div., Edmonton, Alberta and Can. Dep. Agric., Fc Biol. Div., Calgary, Alberta. Mimeograph.

Wotton, D.L.; Jones, D.C. 1976a. A rationalization of spruce budworm control in the Spruce Woods Provincial Park and Forest, Manitoba. Part I. Manit. Dep. Mines Resour. Environ. Manage. Unpubl. Rep. 76-1.

Wotton, D.L.; Jones, D.C. 1976b. A rationalization of spruce budworm control in the Spruce Woods Provincial Park and Forest, Manitoba. Part II. Manit. Dep. Mines Resour. Environ. Manage. Unpubl. Rep. 76-2.